005510.P076 *Patent*

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	)	
POLIVKA ET AL.	)	Examiner: Nguyen, Tuyen T.
Application No.: 10/617,245	)	Art Unit: 2832
Filed: July 9, 2003	)	
For: METHOD AND APPARATUS FOR TRANSFERRING ENERGY IN A POWER CONVERTER CIRCUIT	)	

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION PURSUANT TO 37 C.F.R. § 1.131

Sir:

I, James Y. Go, hereby declare that:

1. Power Integrations, Inc., of San Jose, California, is the assignee of the above-captioned patent application.

2. Power Integrations, Inc., hired our Law Firm, Blakely, Sokoloff, Taylor & Zafman LLP to prepare the above-captioned patent application and represent the inventors William M. Polivka and David Michael Hugh Matthews before the United States Patent & Trademark Office.

4. On June 24, 2003, I received invention disclosure materials provided as Exhibit I in the accompanying 37 CFR § 1.131 Declaration of William M. Polivka and David Michael Hugh Matthews filed herewith.

5. After receiving the invention disclosure materials on June 24, 2003, I began preparing the above-captioned patent application and filed the patent application on July 9, 2003.

I thereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the above-identified application or any patent issued thereon.

Respectfully submitted,

Date 12-14-05

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FIRST CLASS CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail with sufficient postage in an envelope addressed to Mail Stop Amendment, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450

on December 14, 2005
Date of Deposit

Yuko Tanaka
Name of Person Mailing Correspondence

Y. Tanaka
Signature

December 14, 2005
Date

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December 14, 2005	Yuko Tanaka	Y. Tanaka	December 14, 2005
Date Mailed	Name	Signature	Date

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DECLARATION PURSUANT TO 37 C.F.R. § 1.131

Sir:

We, William M. Polivka and David Michael Hugh Matthews, hereby declare that:

1. We are the co-inventors of the above-captioned patent application and the co-inventors of the subject matter described and claimed therein (hereinafter "the present invention").

2. Power Integrations, Inc., of San Jose, California, is the assignee of the patent application described above.

3. We are each employed by Power Integrations, Inc.

4. Prior to July 1, 2002, we conceived of the present invention in this country. July 1, 2002 is the effective PCT date of US Patent Application Publication

2004/0164834 of Tolle et al. (hereinafter Tolle), which has been cited as a 35 USC § 102(e) reference in the above-captioned patent application.

5. Exhibit A is a copy of the Engineering Notebook of David Michael Hugh Matthews. Exhibit A details various experiments relating to circuit and energy transfer element (transformer) configurations dating from December 1999. The entry of 24th January 2000 (page 10 of the exhibit A) details an energy transfer element constructed using what is referred to as a 'dog bone' core. On the same page of Exhibit A is discussion of using a 1 watt resistor as the basis of an energy transfer element although it is concluded that this approach is not very promising due to the bulk of the resulting energy transfer element. In contrast, 2 transformers are wound using the 'dog bone' core, one of which had a leakage inductance of 130 uH which was deemed reasonable for further experimentation (page 10 of Exhibit A). On pages 10 and 11 of Exhibit A are a series of scope waveforms taken using these 'dog bone' core transformers. The measurements were taken using power converter circuits of the type illustrated on pages 2 and 5 of Exhibit A where only the primary or input winding of the energy transfer elements are shown which form the primary or input of a flyback converter. It will be noted from the basic cross section of the 'dog bone' core on page 10 of Exhibit A, that it is an open magnetic structure having an external surface around which at least an input and an output winding are wound without a bobbin. This is further illustrated in the photograph on page 12 of Exhibit A. At the bottom of the photograph on page 12 of Exhibit A are 2 transformer samples constructed using 'dog bone' cores. It should be noted that several terms are used in the art to describe this type of core including 'dog bone', 'I-core', 'drum core' and even 'bobbin core' since the core itself forms the bobbin

that supports the windings. Accordingly, these terms are often used interchangeably. As can be seen in the photograph of page 12 of Exhibit A, the 'drum cores' used to construct the energy transfer elements have an external surface that is curved and though obscured by the first and second windings, the surface around which these windings are wound is cylindrical. Since the 'drum core' magnetic element has an open structure, there is no need to thread the first and second windings through any opening defined by the magnetic element and the windings can instead be wound directly around the external surface of the magnetic element. It can be seen in the photograph of page 12 of Exhibit A, that one of the windings (in this case the output winding of the energy transfer element) comprises triple insulated wire as will be apparent to one skilled in the art from the distinctive yellow color of the winding insulation material which is typically used in low cost triple insulated wire. Though obscured by the triple insulated wire, the first or input winding of the energy transfer element is constructed of magnet wire. The 'drum core' magnetic elements of the photograph on page 12 of Exhibit A have 2 electrically conductive pins mounted to the magnetic element through electrically insulating material. The notes and photograph in Exhibit A therefore illustrate the construction of an energy transfer element with a first winding and a second winding wound around an external surface of a magnetic element without a bobbin, wherein energy is transferred through a magnetic coupling provided by the magnetic element between the first and second windings.

6. We reduced the present invention to practice in this country, with due diligence from a date prior to July 1, 2002 to July 9, 2003, which is the filing date of the above-identified patent application, in this country, as evidenced by Exhibits B through I.

7. Following the experiments detailed in Exhibit A, several confidential presentations and documents were prepared with due diligence during the course of the year 2000. Since the presentations and documents were all confidential (*e.g.*, "Company Confidential," "PI (Power Integrations) Confidential," etc.), they were not available to the general public and therefore do not qualify as prior art references under any paragraph of 35 USC § 102.

8. Exhibit B is a printout of a confidential PowerPoint document entitled "Primary Feedback Techniques: introducing LinkSwitch," dated 2nd June 2000. In Exhibit B, the 'drum core' transformers are shown. However, results with the 'drum core' transformers are not shown since, with the integrated circuit (IC) products that Power Integrations had available at the time of presentation, the results were not as good as the other construction techniques illustrated (slide 9 of Exhibit B). Therefore, the relatively poor results with the 'drum core' transformers supported the fact that research and development of a new IC product would need to continue in order to fully realize the improved results that could be attained with the 'drum core' transformers. As will be discussed in later Exhibits, research and development of the IC product referred to as either the "Buckswitch" or "Linkswitch" IC product, would also continue with due diligence in order to fully reduce to practice and realize the improved results with the 'drum core' types of transformers.

9. Shortly afterwards on the 6th June 2000, another confidential PowerPoint document was prepared, entitled "Low Cost Primary Feedback Switching Supply using LinkSwitch IC Concept." Indeed, as indicated by the title, the Linkswitch was still an IC concept in which research and development would continue with due diligence in order

to fully reduce to practice and realize the improved results with the 'drum core' types of transformers. A printout of this confidential PowerPoint document is attached as Exhibit C, where again the 'drum core' energy transfer elements are shown (slide 9 of Exhibit C) and were discussed in connection therewith.

10. On 22nd Sept 2000, another confidential PowerPoint document was prepared, "Low Cost Primary Feedback Switching Supply using LinkSwitch." A printout of this confidential PowerPoint document is attached as Exhibit D, where the 'I- core' energy transfer element is shown as a "potential transformer construction" (slide 10 of Exhibit D). As shown in slide 10 of Exhibit D, diagram shows the possibility of additionally coating at least a portion of the energy transfer element with a material having a magnetic permeability substantially greater than free space – in the slide this is referred to a 'high permeability epoxy' which may be 'ferrite loaded' which would achieve the high relative permeability as will be understood to one skilled in the art.

11. The I-core construction primary (or input winding) inductance is relatively low compared to alternative magnetic elements with closed magnetic paths like for example torroids, where the windings are threaded through an opening defined in the magnetic element. As will be known to one skilled in the art, this relatively low inductance results in very fast rising (or "high di/dt" as understood to those skilled in the art) current waveforms in the input winding of the energy transfer element when applied to an ac/dc converter such as a flyback converter.

12. In order to effectively evaluate and fully appreciate the high di/dt attributes of the I-core transformer for purposes of reduction to practice, research and development continued at Power Integrations throughout 2001 for an IC product family specifically

designed to accommodate such very high di/dt's. As understood and accepted to those skilled in the art, research and development of an IC family is generally a long and complex undertaking by a company.

13. Following the continued background research for the IC family, the first Objective Technical Specification (OTS) for such an IC device was prepared. A printout of this confidential ("PI Confidential") Objective Technical Specification, entitled "Product Concept/Preliminary OTS Buck Converter Family (*BuckSwitch*)," dated 15th February 2002 is attached as Exhibit E. Notes L and M on page 5 of Exhibit E refer specifically to the need to cope with very high di/dt's, which could be used effectively with I-core types of transformers to realize the high di/dt's.

14. From the time of the production of Exhibit E, work continued internally at Power Integrations to research, develop and qualify to production an IC product family with the desirable feature of being possible to use in applications with high di/dt's, which could be used with the I-core types transformers when completed. As mentioned earlier, it should be noted that this IC product family started development with an internal code name 'BuckSwitch', but before final release, was renamed 'LinkSwitch-TN'.

15. On 13th November 2002 a confidential internal document was prepared in which specific mention was made of the use of the 'BuckSwitch' in flyback converters. A printout of this confidential PowerPoint document entitled "BuckSwitch Introduction" is attached as Exhibit F. As noted above, the ability to operate with high di/dt's would make it ideal for use with an I-core energy transfer element in a flyback converter configuration. Slide 9 of Exhibit F gives specific details of the di/dt specifications under which the current limit of each device is specified. The 75 mA/usec value being a typical

value under low voltage input conditions but a 500 mA/usec specification also being given due to the very high di/dt's that are exhibited in power converters with low inductance energy transfer elements.

16. On 2nd April 2003, with BuckSwitch IC samples finally available for testing with an I-core type transformer, a specific proposal for a series of tests using the BuckSwitch samples with an I-Core transformer was made. An e-mail message originating from David Michael Hugh Mathews ("Mike Matthews") regarding the same is attached in Exhibit G.

17. On 25th April 2003, results of the BuckSwitch operation with an I-core transformer were documented and have been attached in Exhibit H.

18. With the successful testing and evaluation of the I-core transformer now finally documented, on 23rd June 2003, invention disclosure materials including drawings and text were prepared by William M. Polivka and David Michael Hugh Matthews and sent to patent attorney James Y. Go on 24th June 2003 for the purpose of preparation and filing a corresponding patent application. The drawings and text of the invention disclosure materials have been attached in Exhibit I.

19. On 9th July 2003, the above-captioned patent application was filed with the United States Patent & Trademark Office.

We thereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of

the United States Code, and that such willful false statements may jeopardize the validity of the above-identified application or any patent issued thereon.

Respectfully submitted,

Date 14 DECEMBER, 2005

William M. Polivka

Date 14th December, 2005

David Michael Hugh Matthews

Confidential & Privileged Attorney-Client Communication

Date	Event	Exht
24/January/2000	First reference to I-core transformer in Mike's notebook	A
2/June/2000	Presentation on LinkSwitch project progress	B
6/June/2000	Presentation to Friwo	C
22/September/2000	Presentation to HiCal showing I-Core transformer construction	D
15/February/2002	First release of Preliminary OTS for BuckSwitch. Transformer not addressed.	E
13/November/2002	BuckSwitch presentation by Stefan mentions flyback topology possible	F
2/April/2003	Note from Mike to Stefan suggesting evaluation of BuckSwitch in LinkSwitch configuration with I-core and high permeability dip coating.	G
25/April/2003	Stefan documents operation of I-core transformer with BCK301	H
7/May/2003	Invention Disclosure Materials	I

Product Concept/Preliminary OTS
Buck Converter Family (*BuckSwitch*)

Content

Management Overview / Strategy Relationship and Customer Requirements

Since *TOPSwitch* was introduced in 1995 we have had limited success in very low power applications where galvanic isolation is not required. Unlike an isolated power supply - that is typically realized in the flyback topology - a transformer is not normally used in switching non-isolated solutions but replaced with a simple choke. The two most dominant topologies are either buck or buck-boost converters. We had a first success with Siemens in programmable logic control (PLC) and motor protection controls with TOP221 in 1996 and later on with *TinySwitch* and *TinySwitch-II* available in domestic and personal care appliances with AKO or Braun amongst others. However, as all the *TOPSwitch* and *TinySwitch* families have been developed with mainly the flyback topology in mind our product feature set has not been optimised to address these applications on a wider base. This family of products is therefore designed to address the specific needs of off-line buck or buck-boost converters.

Buck and buck-boost converters are very much driven by the output current, as the switching MOSFET has to conduct the full output current (there is no transformer turns ratio). Thus the respective output voltage determines the available output power. With this new family we will be able to deliver as much as 175 mA of output current. Most of the applications will have output voltages ranging from 5 to 15 V, hence the delivered output power will stay in the sub 2.5 W range. Focus applications are any low power non-isolated power supplies including domestic and personal care appliances, industrial and motor control, timers, digital programmable thermostats, utility meters, garage door openers, and other wall mounted controls with LCD displays.

All these applications are following a trend towards expanded features (such as displays) demanding higher output power/current in the area of 50 to 175 mA. Existing passive solutions will not be able to fulfill this increased demand cost effectively opening up the field for this new family. Upcoming standby and no-load requirements are also driving those applications towards the products described here. Last but not least customers are looking to simplify their logistics using universal input voltage circuits and have the capability to use more SMD components in manufacture, which again is not possible with existing passive solutions.

Competitive Product Analysis

The majority of existing competition in this low current non-isolated power supply area is passive solutions capable to deliver up to 60-70 mA of output current. These same solutions can supply more output current become less cost effective. Therefore, for higher output currents the competition is likely to be buck converters based on either discrete solutions like 600 V MOSFET plus timer/PWM IC or integrated solutions such as VIPer12 from STMicroelectronics or TEA1520 (STARplug) from Philips. Both devices (in a SMD package on tape & reel) have been quoted below $0.30. Other potential integrated solutions include NCP105X from ON Semiconductor or FSDHX65 from Fairchild. However, like TOPXXX and TNYXXX, all these devices have been designed with flyback converters in mind and therefore are not optimised for buck or buck-boost applications.

Passive solutions can be divided into three groups:
a) Simple resistive power supplies up to ~25-30 mA of output current. This solution is very low cost but suffers from a very low efficiency (typ. 5 %). Also the increased current consumption of applications such as appliance controls and the ever-increasing demand for energy efficient solutions will make them obsolete sooner or later.
b) Capacitor-fed power supplies (cap dropper) which are based on the charge pump principle. As the input capacitor is connected directly across AC mains very often safety rated types (i.e. X2 rating) are used, as otherwise extra components are required to meet surge requirements. With a full bridge rectification scheme and a 1.5 µF capacitor the typical output current is about 93 mA, however with all tolerances included this drops to about 65 mA. Key disadvantages are large physical size (in particular the X2 cap), low efficiency, limited input voltage range and high no-load consumption (power consumption with this type of circuit is actually constant independent of output load). Details on this type of power supply are provided in the customer feedback section in Appendix B.
c) Linear transformer power supplies with post regulation. Key disadvantages are low efficiency, large physical size and weight, limited input voltage range, and high no-load consumption which makes it difficult to meet the EU 300 mW requirement.

System cost analysis shows that the replacement cost for BCKxx1 (the smaller of the two devices specified in this document) ranges between $0.255 in worst case and $0.445 in best case when compared to integrated switching solutions. When compared with cap droppers (X2 rated input cap with bridge rectifier) the replacement cost for BCKxx1 equals to $0.19 for a 65 mA supply and $0.29 for a 130 mA supply. Please see Appendix D for further details.

Time Scale and Resources

Timing from start of the project to product release is targeted at 8-10 months. The resource to achieve this will be decided following discussion with the groups involved. Typical timing from the final OTS to tape out is in the order of 3 months. Subsequent qualification is a further 4 months. The overall time of 8-10 months is therefore regarded as a reasonable target.

Product Description and Performance

<u>Pin Description</u>

BP.......... Bypass/Vcc
S .... Source (including HV return)
EN......... Enable
D .... Drain

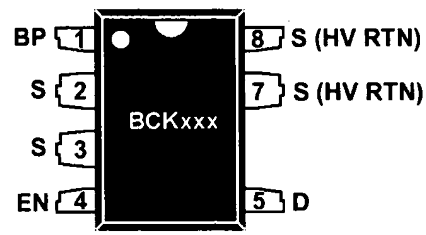


Figure 1. DIP-8/SMD-8 package

<u>Packages</u>

Initially the DIP-8 (P package) and SMD-8 (G package) are the preferred packages. The Leadframe and pin-out are identical to those used with TNY264 providing an increased creepage on the package by eliminating pin 6. However, customers are continuously asking for smaller package (size and height) to reduce PCB space consumption. Additionally the SMD-8 package is difficult to handle in automated production lines causing reduced yields. This market is also extremely competitive. Therefore it should be considered to introduce smaller and lower cost packages such as DIP-4/SMD-4 and SOIC-8 in future. Key to introducing these smaller packages however is to understand creepage distances and thermal performance in addition to molding compounds and assembly considerations

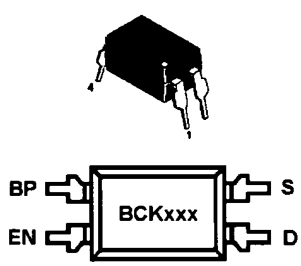


Figure 2. DIP-4 package

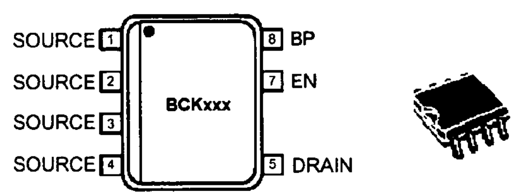


Figure 3. SOIC-8 package

Specifications

General System/Component Requirements:

A. Output current range: 0–175 mA in mostly discontinuous mode (MDCM). In order to get the power supply running in MDCM, the internal minimum current limit has to be twice the DC output current. Customers can to run the converter in fully continuous mode of operation (CCM) with to get higher output currents. CCM however, introduces additional losses dependent on the freewheeling diode reverse recovery time. See Appendix E for further details.

B. Likely to be two devices:

Device Type	Min. Current Limit	$R_{DS(ON)}$ (max @ T_J=100 °C)	Target Output Current Capability
BCKxx1	250 mA	48 Ω	120 mA
BCKxx2	350 mA	24 Ω	150 mA

The output power capability depends on the chosen output voltage. For further details regarding maximum output current capability see Appendix E. Devices having higher output current capability are not considered since a non-isolated flyback converter becomes more attractive at higher output currents.

C. $R_{DS(ON)}$ for BCKxx1 is identical to TNY264's. $R_{DS(ON)}$ for BCKxx2 is specified to have the same conduction losses at low line as with BCKxx1 assuming that both designs are running in MDCM at this input voltage.

D. Input voltage range: 85-265 VAC or 85-375 VDC. With a 700V breakdown voltage the devices could be operated at 3 phase mains too, though switching losses may be the limiting factor.

E. Control: Digital On/Off with an inverted Enable pin logic compared to TNY254 (i.e. a switching cycle is skipped as soon as the current fed into the pin exceeds 50 μA). An Enable pin hysteresis current is not required. This control scheme allows also meeting the European 300 mW requirements during no-load conditions. See Appendix C for further details.

F. Minimum switching frequency should be 62 kHz. This provides a DCM capability up to 100 mA with a 15 V output from universal mains employing a standard 1 mH ±10 %, 300 mA choke. Maximum switching frequency should stay below 75 kHz to keep the 2nd harmonic below 150 kHz (starting frequency of EN55022). Frequency jitter is not required.

G. Duty cycle range: 0-67 %
The high maximum duty cycle of 67% allows to use this family in lowest-cost low power flyback converters too. In addition, if auto-restart is included (see Note K), the high duty cycle will allow regulation to very low input voltages. This helps alleviate the normal output voltage glitches characteristic of devices with auto-restart function and no UVLO feature at turn off since the Drain high voltage current source no longer has enough voltage to keep the device running.

H. Audio noise reduction is not required because of the use of standard off-the-shelf chokes with no air gap.

I. Thermal shutdown temperature should be raised to minimum +135 °C. Many appliances are specified at high ambient temperatures such as +85 °C and +105 °C.

J. The device should have an internal Bypass pin clamp of 6.3 V allowing external biasing in high ambient applications, which in turn will reduce power dissipation inside the device.

K. Auto-restart is required to protect the power supply in case of open control loop. Short circuit protection is inherently given in buck converters through the internal current limit of the device. The startup time of an example buck converter has been measured as long as 46ms (85 VAC, 12 V, 100 mA, C_{OUT}=330 µF, see Appendix C). Hence an Auto-restart on time of 50ms would be advisable. The Auto-restart duty cycle should be less than 10% to allow clamping the output to safe levels in open control loop conditions with low cost zener diodes. Auto-restart should be implemented such, that by shorting the Enable pin to Source it will be disabled. This will allow open-loop converters and could be useful during testing to disable the function if necessary.

L. Buck converters will typically use a smaller inductance than flyback converters, which in turn will lead to significantly steeper current slopes (high di/dt). In order to limit the current limit overshoot and to allow customers to compute the worst case output power the maximum current limit delay time should be limited to 100ns. This current limit delay can be specified at a very high di/dt since this is the condition under which it is most important for the customer to know the worst case performance. This parameter also needs to be specified over temperature.

M. Absolute maximum peak drain current (SOA) should be specified for both topologies buck/buck-boost and flyback. Buck converters don't have to cope with flyback voltages so that a SOA rating at 400 V is more applicable. An absolute maximum peak drain current of 500mA or higher for the BCKxx1 would allow the use of a standard 330 µH ±10 % choke in a 5 V, 100 mA buck converter at universal input. The values for BCKxx2 are chosen to be identical with TNY266 and scaled for the 400 V rating accordingly. See also Note L and P.

N. Initial current limit should be specified at min. 100% of the internal current limit. This would allow customers to operate the buck converter in continuous mode delivering higher output power. With this functionality it may not even be necessary mention this specification in the parameter table.

O. The BYPASS pin should act as a local low voltage supply. This will allow supplying a local optocoupler for control loop purposes. The current sourcing capability should be therefore at least the maximum Enable Pin Turnoff Threshold Current. This parameter does therefore need to be specified to be useful to the customer. A minimum supply current at 50V DC rail and above should be specified.

P. Minimum leading edge blanking time is chosen to allow customers to use the devices in continuous mode as well. With an ultra-fast free-wheeling diode and 3.25 mH buck choke (considered to be a worst case condition) the leading edge current pulse width has been measured at 165 ns at 265 VAC (see Appendix C). The maximum blanking time is set to guarantee a maximum minimum on-time of the devices of $t_{LEB(MAX)} + t_{ILD(MAX)}$ = 360 ns. With a SOA rating of 500 mA at 400 V for the BCKxx1 this will allow to use a 330 µH ±10 % choke for a 5 V, 120 mA output. See also Note L and M.

Q. Breakdown voltage of less than 700 V was considered, however some customer feedback indicated that any voltage less than 600 V would create concern in the market (mains transients). Furthermore the results of Appendix C show that on resistance is not the critical factor in thermal performance since device dissipation is highest as high line where switching losses dominate.

ABSOLUTE MAXIMUM RATINGS[1]

DRAIN Voltage .... -0.3 V to 700 V
Peak Drain Current (BCKxx1)[2] ....500 mA
Peak Drain Current (BCKxx1)[3] ....400 mA
Peak Drain Current (BCKxx2)[2] .... 700 mA
Peak Drain Current (BCKxx2)[3] .... 560 mA
ENABLE Voltage .... -0.3 V to 9 V
ENABLE Current ....100 mA
BYPASS Voltage .... -0.3 V to 9 V

Storage Temperature .... -65 to 150 °C
Operating Junction Temperature[4] .... -40 to 150 °C
Lead Temperature[5] ....260 °C

Notes:
1. All voltages referenced to SOURCE, T_A = 25 °C
2. At 400 V Drain voltage. *(See Note M)*
3. At 700 V Drain voltage. *(See Note M)*
4. Normally limited by internal circuitry.
5. 1/16" from case for 5 seconds.

THERMAL IMPEDANCE

Thermal Impedance: P/G Package:
(θ_{JA}) ....45 °C/W[2]; 35 °C/W[3]
(θ_{JC})[1] .... 11 °C/W

Notes:
1. Measured on the SOURCE pin close to plastic interface.
2. Soldered to 0.36 sq. inch (232 mm^2) 2oz. copper clad
3. Soldered to 1 sq. inch (645 mm^2) 2oz. copper clad

Parameter	Symbol	Conditions SOURCE = 0 V; T_J= -40 to 125 °C See Figure TBD (Unless Otherwise Specified)		Min	Typ	Max	Units
CONTROL FUNCTIONS							
Output Frequency	f_{OSC}	T_J = 25 °C *See Note F*		62		70	kHz
Maximum Duty Cycle	DC_{MAX}	S1 Open		66	68	71	%
ENABLE Pin Turnoff Threshold Current	I_{DIS}	T_J = -40 °C to 125 °C		30	50	68	µA
		T_J = 125 °C		45	52	68	
ENABLE Pin Voltage	V_{EN}	I_{EN} = 25 µA		TBD		TBD	V
ENABLE Pin Short-Circuit Current	I_{ENSC}				TBD		µA
DRAIN Supply Current	I_{S1}	V_{EN} = TBD V (MOFET Not Switching)	BCKxx1		TBD		µA
			BCKxx2		TBD		
	I_{S2}	ENABLE Open (MOSFET Switching)	BCKxx1		TBD		µA
			BCKxx2		TBD		
BYPASS Pin Charge Current	I_{CH1}	V_{BP}= 0 V T_J = 25 °C	BCKxx1		-3.3		mA
			BCKxx2		-4.6		
	I_{CH2}	V_{BP}= 4 V T_J = 25 °C	BCKxx1		-2.0		
			BCKxx2		-3.0		
BYPASS Pin Voltage	V_{BP}			TBD	5.8	TBD	V
BYPASS Pin Voltage Hysteresis	V_{BPH}				0.72		V
BYPASS Pin Short-Circuit Current	I_{BPSC}	*See Note O*	BCKxx1	68		TBD	µA
			BCKxx2	68		TBD	

Parameter	Symbol	Conditions SOURCE = 0 V; T_J= -40 to 125 °C See Figure TBD (Unless Otherwise Specified)		Min	Typ	Max	Units
CIRCUIT PROTECTION							
Current Limit	I_{LIMIT}	di/dt = TBD mA/µs T_J = 25 °C, *See Note A*	BCKxx1	250		288	mA
		di/dt = TBD mA/µs T_J = 25 °C, *See Note A*	BCKxx2	350		403	
Leading Edge Blanking Time	t_{LEB}	T_J = -40 °C to 125 °C *See Note P*		180		260	ns
Current Limit Delay Time	t_{ILD}	T_J = -40 °C to 125 °C *See Note L*				100	ns
Thermal Shutdown Temperature	T_{SD}	*See Note I*		135		155	°C
Thermal Shutdown Hysteresis	T_{SDH}				75		°C
OUTPUT							
ON-State Resistance	$R_{DS(ON)}$	BCKxx1 I_D = 25 mA, *See Note C*	T_J = 25 °C		28	32	Ω
			T_J = 100 °C		42	48	
		BCKxx2 I_D = 35 mA, *See Note C*	T_J = 25 °C		14	16	
			T_J = 100 °C		21	24	
OFF-State Leakage	I_{DSS}	V_{BP} = 6.2V, V_{EN} = 0V V_{DS} = 560 V, T_J = 125 °C				50	µA
Breakdown Voltage	BV_{DSS}	V_{BP} = 6.2V, V_{EN} = 0V I_{DS} = 100 µA, T_J = 25 °C		700			V
Rise Time	t_R	Measured in a Typical Buck Converter Application			TBD		ns
Fall Time	t_F				TBD		ns
Drain Supply Voltage				TBD			V
Output Enable Delay	t_{EN}	See Figure TBD				10	µs
Output Disable Setup Time	t_{DST}				0.5		µs
Auto-Restart ON-Time	t_{AR}	T_J = 25 °C *See Note K*			50		ms
Auto-Restart Duty Cycle	DC_{AR}					10	%

Other Comments

Investigations have to be performed to clarify how much additional die size is required to add Auto-restart (either digital, analogue or mixed). Once the results concerning the additional cost are available a business decision has to be taken whether it should be incorporated or not.

Powerline communication (PLC) might become a hot topic in major appliances such as washers or fridges in future. In order to understand the impact of the current target switching frequency (62-70 kHz) further investigation has to be done with both, customers already using or planning to use PLC and suppliers of PLC solutions (e.g. Echelon).

Technology

The technology will mainly use existing building blocks from *TinySwitch* and *TinySwitch-II*. Packages are likely to be DIP-8 and SMD-8 in the beginning. Preferred leadframe is that of the TNY26X due to the increased creepage. Later introduction of smaller packages such as DIP-4 and SOIC-8 is desirable to fulfill customer's on-going request for system cost reduction and space savings in future.

Schedule for Review

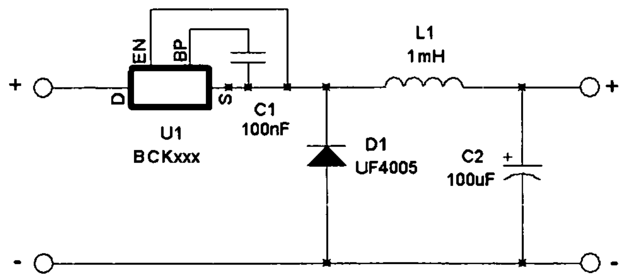
TBD

Revision History

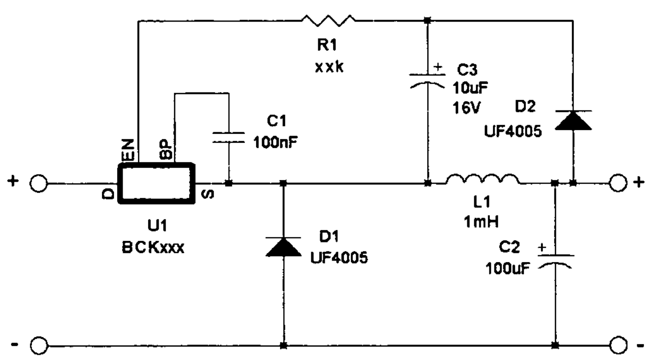
Date	Author	Revision	Description & changes
15-Feb-02	STB	A	First release

Appendix A - Circuit Examples and Control Schemes

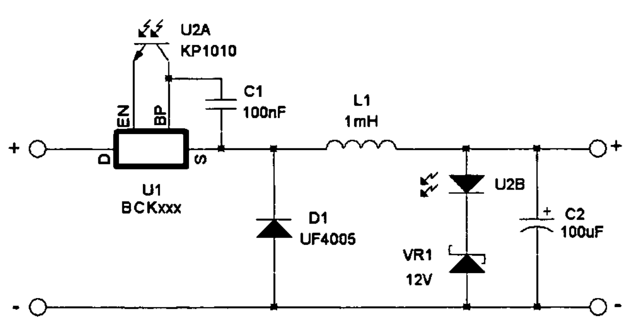
Buck with Open Control Loop

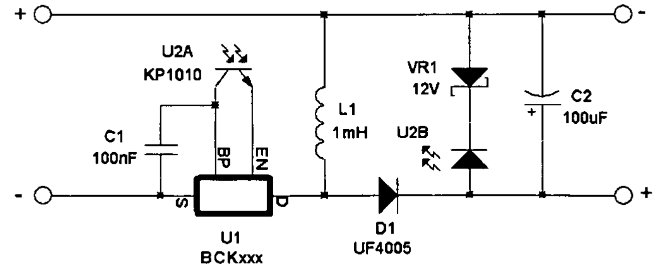


Buck with Bootstrap Control



Buck and Buck-Boost with Optocoupler Control





Appendix B - Customer Feedback

Diehl-AKO

Date: 01/25/02
Attendees: Roland Müller, Helmut Natterer, Harald Mangold, STB
Subject: Discussion features BuckSwitch, current low power solutions

Preferred Buck IC features & specifications

- Internal current limit: min. 250 mA (allows IO=120 mA in DCM)
- Switching frequency: chosen such that 15V/120mA are possible with 1mH inductor (worst case)

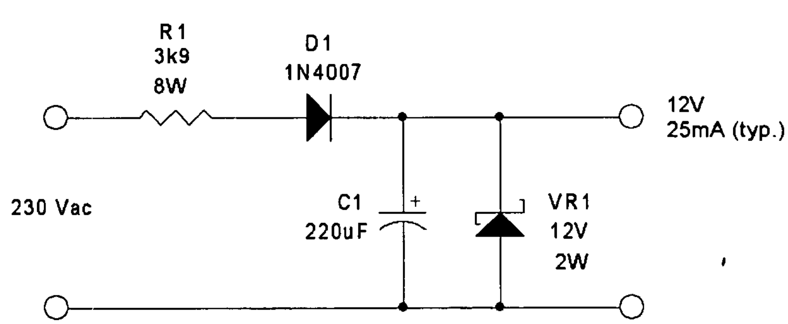
$$f_{SW\_Min} = \frac{2 \cdot 15V \cdot 120mA \cdot (\sqrt{2} \cdot 265V - 8V - 15V)}{0.25mA^2 \cdot 0.9mH \cdot (\sqrt{2} \cdot 265V - 8V)} = 61375Hz$$

- BVD_{SS}: min. 600 V (complies with current IGBT ratings in HV bus), maybe 400 V for the US market
- Auto-restart: not required (short-circuit protection typically not required in such applications due always connected load, failing in a safely manner is admissible)
- Frequency jitter: no (large RFI filter at the input anyway)
- Thermal shutdown: not required, if it comes with no extra cost then larger hysteresis is preferred
- Package: true SMD package to increase production yield (D-PAK, SOT-223, SOIC-8)
- *EcoSmart*: <300 mW during zero load desirable
- Control: no opto-coupler feedback (leakage current problems at elevated temperatures and high humidity, typically large package), ideally resistor divider at the output connected to internal bandgap reference
- No initial current limit (would allow to use CCM in certain applications)
- Audio noise is at very low levels with current TNY254 designs and therefore acceptable
- Integrated free-wheeling diode?

Misc.:
- typically two outputs (12 V relay and 3.3 V or 5 V for µC)
- tests include shortening and opening of any component (according to EN55014), sometimes customers ask for special tests

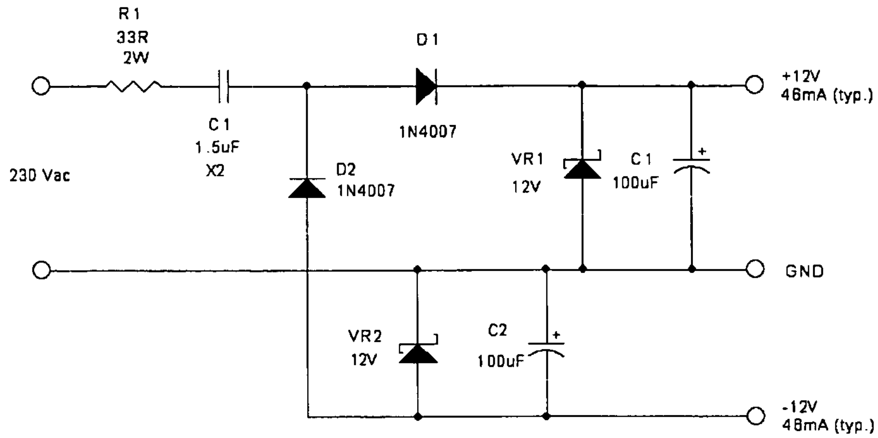
Current/previous low power passive solutions:

a) resistive power supply



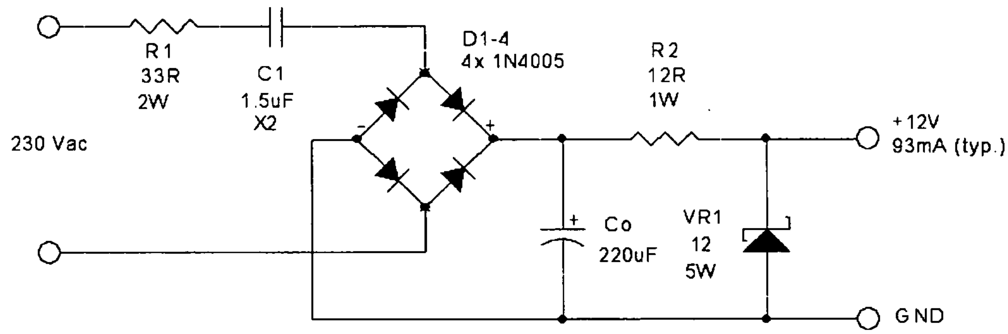
Used in millions of appliance controls. No new design since 2-3 years due to increased current demand of control units.

b) cap dropper (dual output, half-wave rectification)



Preferred current solution for low power controls (negative output used to drive TRIAC). AKO employs 4 different X2 rated cap sizes: 0.47 µF, 0.68 µF, 1 µF, and 1.5 µF (all 10 % tolerance). 1.5 µF X2 cap is prized at € 0.24 at ~1 million pcs.

c) cap dropper (bridge rectification)



Possible, but not preferred topology as missing common ground required extra efforts to drive TRIACs.

$I_O = 4 \cdot f_L \cdot C_1 \cdot (\sqrt{2} \cdot V_{IN} - V_O - V_D)$
(Nathan O. Sokal: A capacitor-fed, Voltage-step-down, single phase, non-isolated rectifier, APEC 1998)

<u>Other European Customer Feedback</u>

Ariston Merloni (01Feb02)
Use cap droppers in washers and refrigerators, up to 1M/y, topology is half-wave rectification to get common ground, with 1.5uF X2 cap they get up to 60mA (splitted between 5V and 12V outputs), BOM cost target: € 0.75 ($0.65) not including PCB

B/S/H Bosch und Siemens Hausgeräte (Feb02)
Use cap droppers up to Po=0.6-0.7W in stove controls (up to 400k/y). Not used in wet, dry or cold appliances. Maximum used X2 cap size is 1.5uF

Whirlpool (Feb02)
All medium range and high-end washers use electronic power supplies. Still use cap droppers (230V, 49mA, 30V output zener chain) in dishwashers. 1.5uF capacitor (no X rating) with parallel 220k resistor (to meet safety). Power supply has input protection (275V varistor).

Somfy (Nov02)
New design for roller blind control: 230Vac, 12V, -20C to +85C, no interference at 433MHz (radio control carrier frequency). Surge 2kV OK, 2-4kV destruction w/o fire acceptable. Will use 500k-1M beginning of 2003. Lowest physical dimension is at premium.

Braun (Dec01)
Use cap dropper with bridge rectification to generate 28V/70mA output for the oscillator charging toothbrush handsets. Annual volumes are around 15M. Cost target € 0.45 ($0.39) including PCB.

Invensys (May01)
Visited site in Germany uses about 1.2M cap droppers in stove controls (5-15V up to 50mA). Cost target is € 0.50 ($0.43).

<u>US Customer feedback provided by John Olliver on 15-Feb-02</u>

System Sensor
Major OEM for Smoke alarms and sensors. 50% of their products are battery powered. Current drawing is from 50uA to 100mA. They are very interested in PI solution for their new offline product (current should be higher than 50mA). EAU up to 500K

First Alert
Major OEM for Smoke alarms and sensors. Current drawing is 25mA to 100mA. Using TNY253P or TNY254P Buck for European model. EAU 300K to 500K

Emerson
Industrial control applications. Current drawing is 100mA to 150mA. TNY266P Buck is been used. EAU 300k.

Milwaukee Electric Tools
Power Tools. 12V output @ 100mA. Using TNY254P Buck. EAU 100K+

Black and Decker
Power Tools. 5V output at 8mA. Current solution resistor dropper and will switch to TNY254P Buck for low power consumption. EAU M+

GE Appliance
Appliances. 12V output @ 100mA. Using TNY254P Buck. EAU 800K

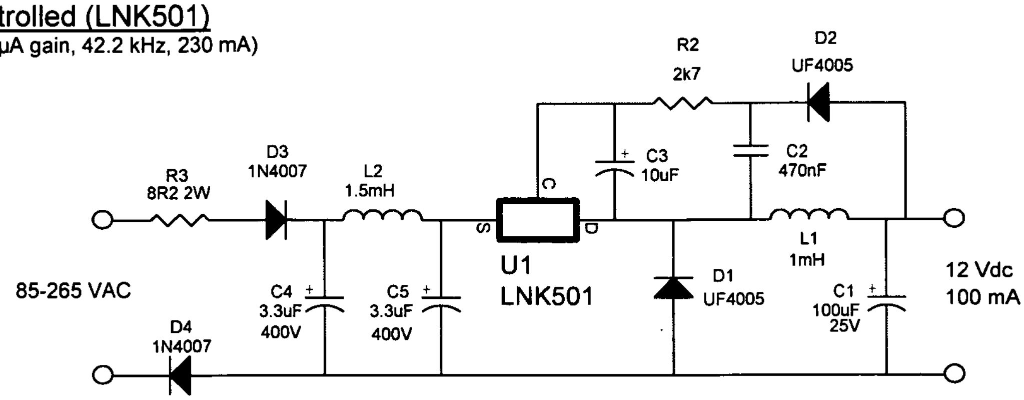
Maple Chase
Smoke Alarms. EAU of 500K. Output current not available.

Whirlpool
Refrigeration Control. Current output between 200mA to 300mA. Usage would be at least a million pcs. Best estimate of pricing is from $0.60 to $0.75.

Appendix C – Evaluation Results PWM vs. On/Off based Buck Converters

A comparison between a PWM controlled (LNK501) and On/Off controlled (TNY254) buck converter has been performed. Both supplies are providing a 12 V, 100 mA output from universal mains with an off-the-shelf 1 mH, 280 mA choke. The control was done in both cases with a bootstrap circuit. The results of both converters are presented below. At the end a comparison chart between the key aspects/differences of both control methodologies is presented.

PWM Controlled (LNK501)
(DC4DC, 324 µA gain, 42.2 kHz, 230 mA)

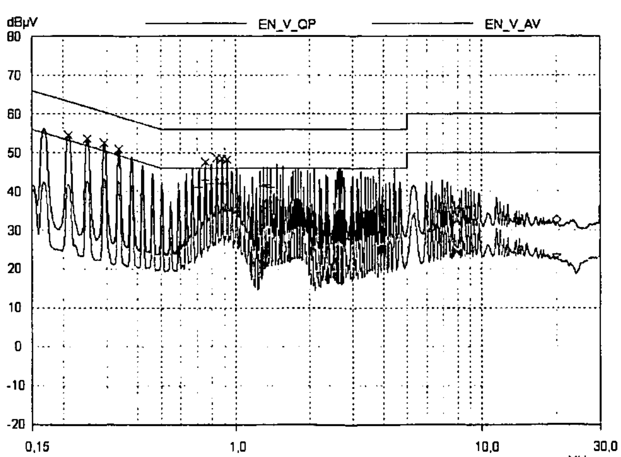


Schematic LNK501 bootstrap controlled buck converter

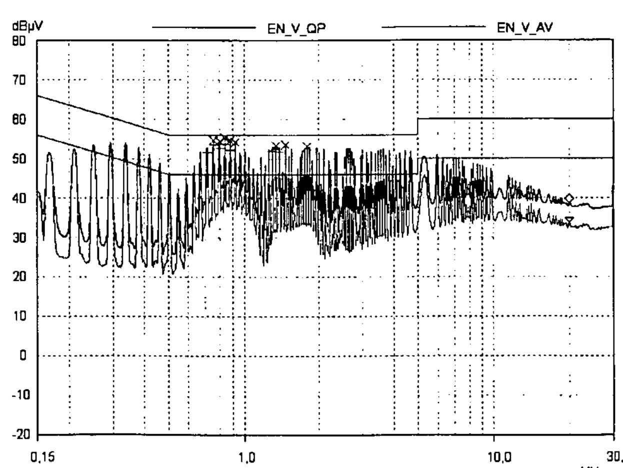
Input Voltage	85 VAC	265 VAC
V_O @ 1 mA load	12.65 V	15.6 V
P_{IN} @ 1 mA load	62 mW (30 kHz)	115 mW (30 kHz)
V_O @ 100 mA load	11.2 V	11.36 V
η @ 100 mA load	73% (40 kHz)	68% (30 kHz)

Performance results LNK501 based buck

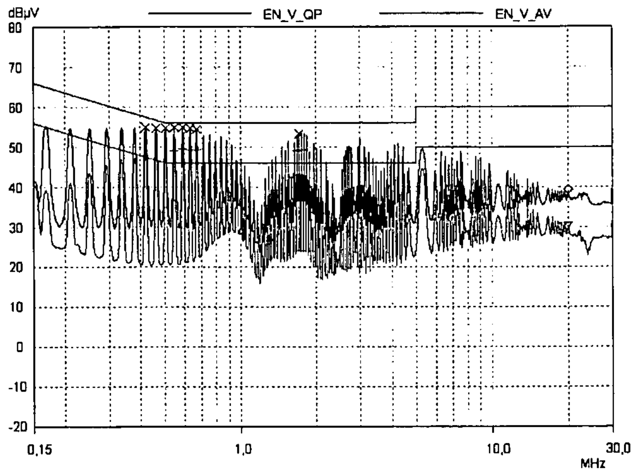
Note: The converter required a small pre-load (~ mA) to maintain the 12 V output at safe levels. The load regulation at light load depends on the size of C2 (470nF). C3 has to be 10 µF to guarantee a safe start-up at full load.



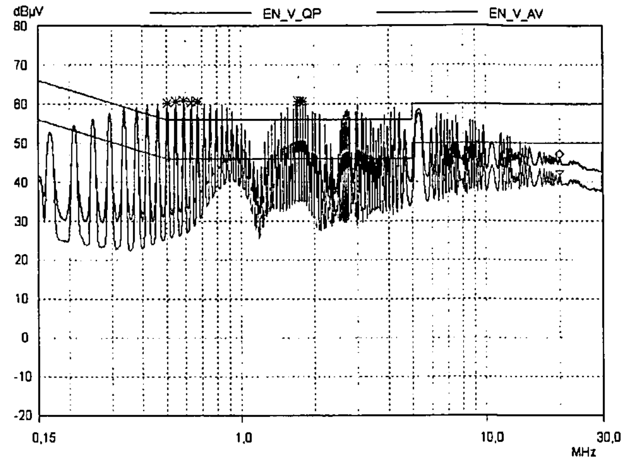
Conducted EMI LNK501, 115 VAC, L1



Conducted EMI LNK501, 115 VAC, N

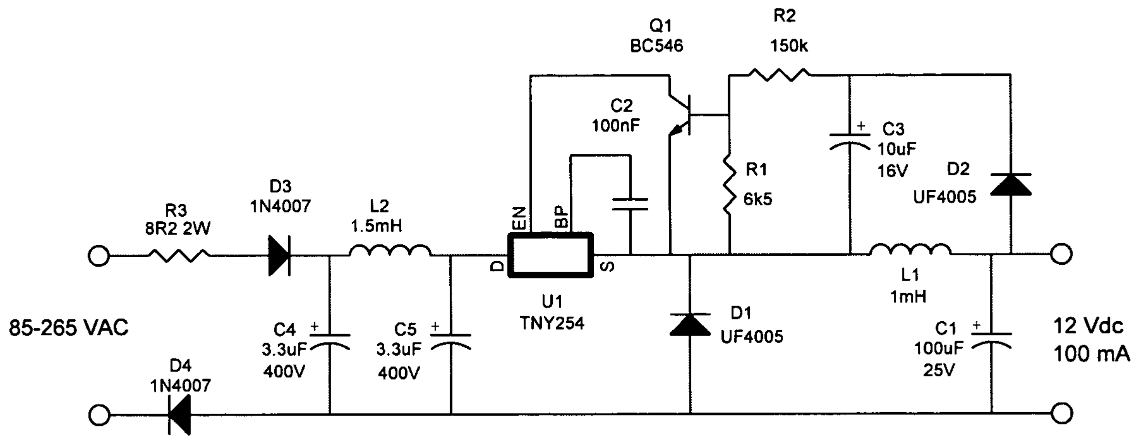


Conducted EMI LNK501, 230 VAC, L1



Conducted EMI LNK501, 230 VAC, N

On/Off Controlled (TNY254)

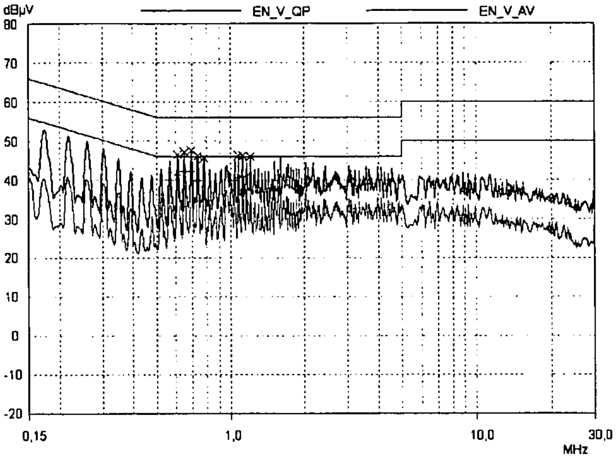


Schematic TNY254 bootstrap controlled buck converter

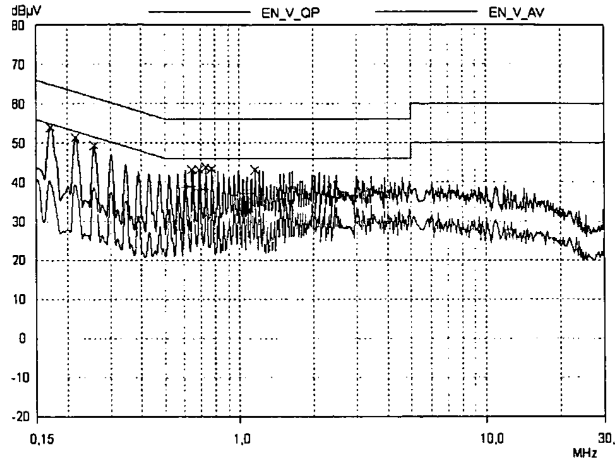
Input Voltage	85 VAC	265 VAC
V_O @ 1 mA load	13.4 V	13.5 V
P_{IN} @ 1 mA load	38 mW	74 mW
V_O @ 100 mA load	12.09 V	11.70 V
η @ 100 mA load	73%	67%

Performance results TNY254 based buck

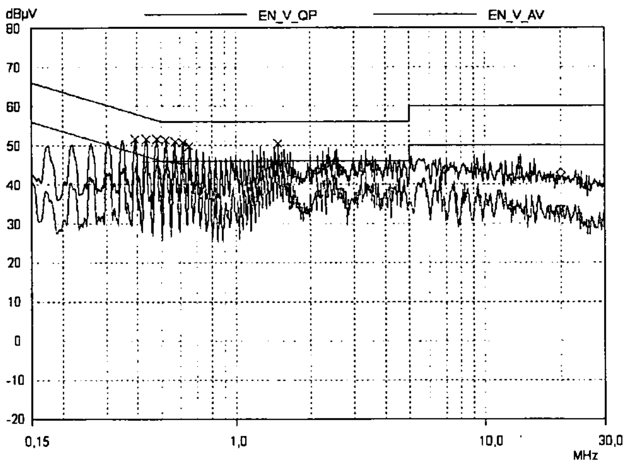
Note: The converter required a small pre-load (~ mA) to maintain the 12 V output at safe levels. The load regulation at light load depends heavily on the size of C3 (10 µF).



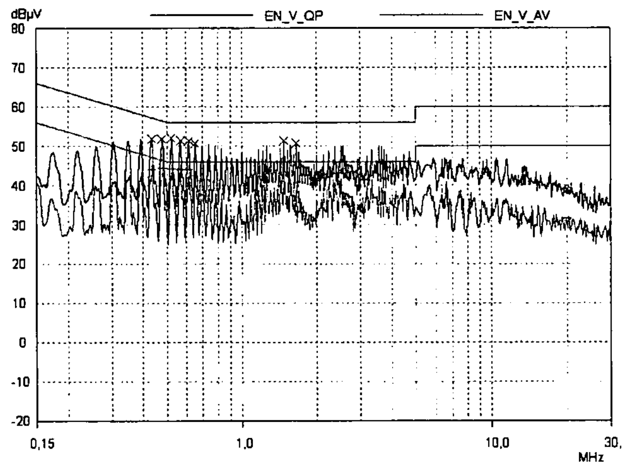
Conducted EMI TNY254, 115 VAC, L1



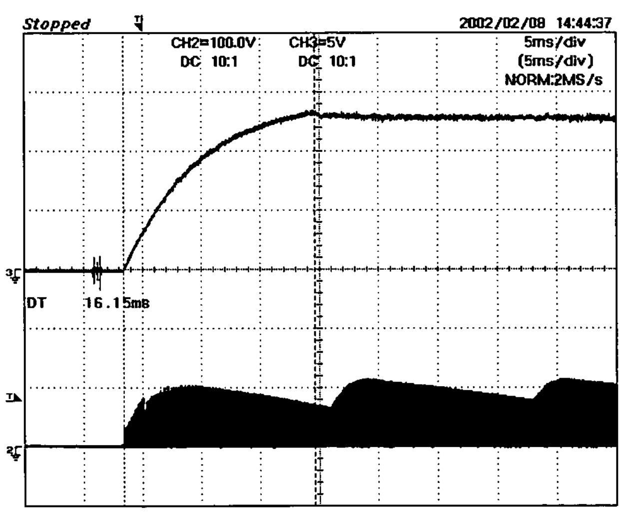
Conducted EMI TNY254, 115 VAC, N



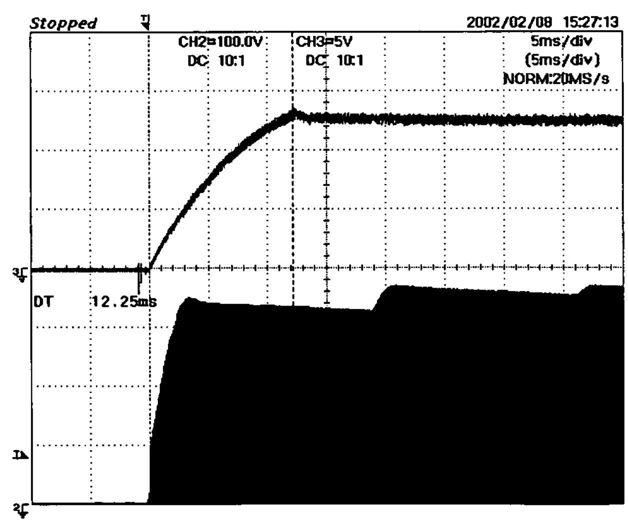
Conducted EMI TNY254, 230 VAC, L1



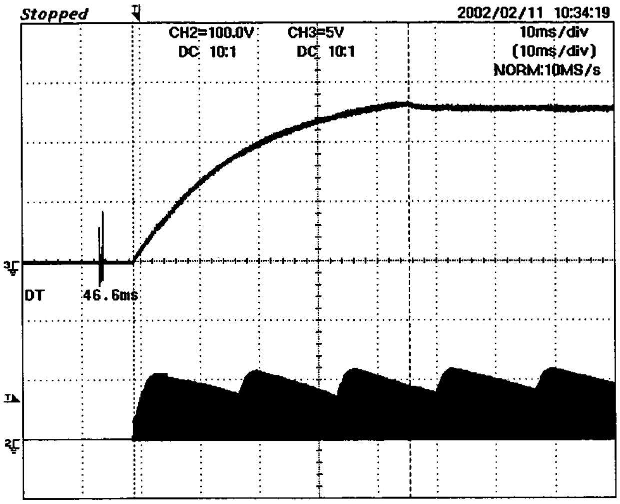
Conducted EMI TNY254, 230 VAC, N



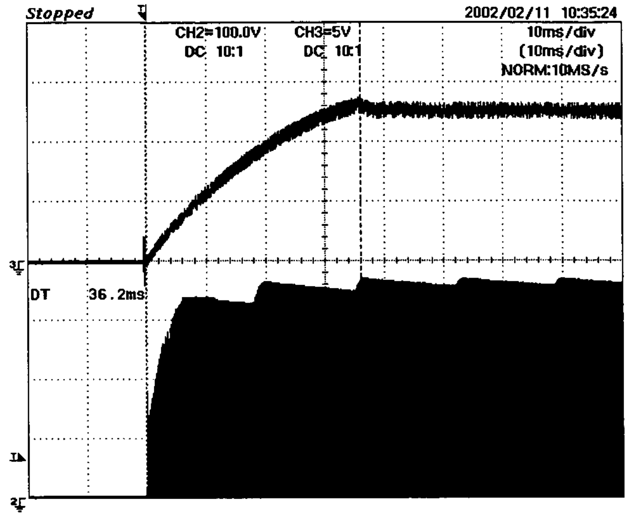
Startup, 85 VAC, 120 Ω, 100 µF output cap [16.15 ms]



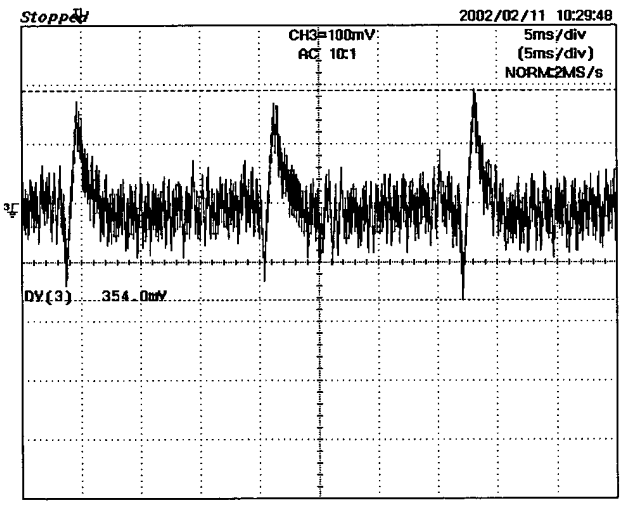
Startup, 265 VAC, 120 Ω, 100 µF output cap [12.25 ms]



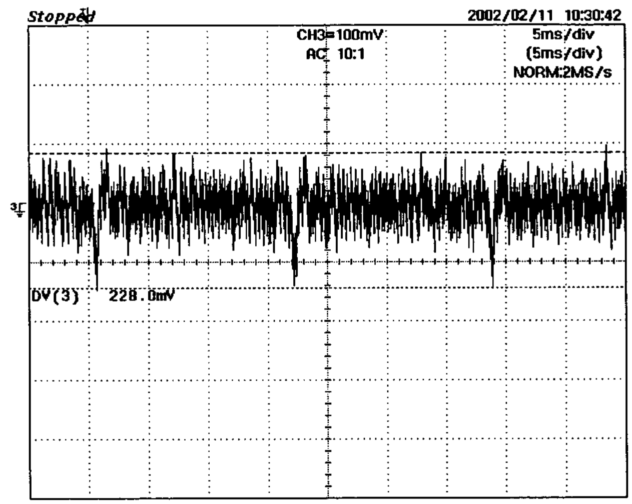
Startup 85 VAC, 120 Ω, 300 µF output cap



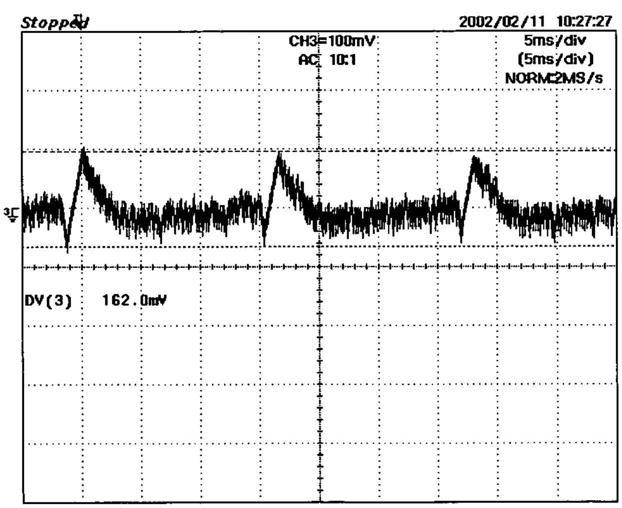
Startup 265 VAC, 120 Ω, 300 µF output cap



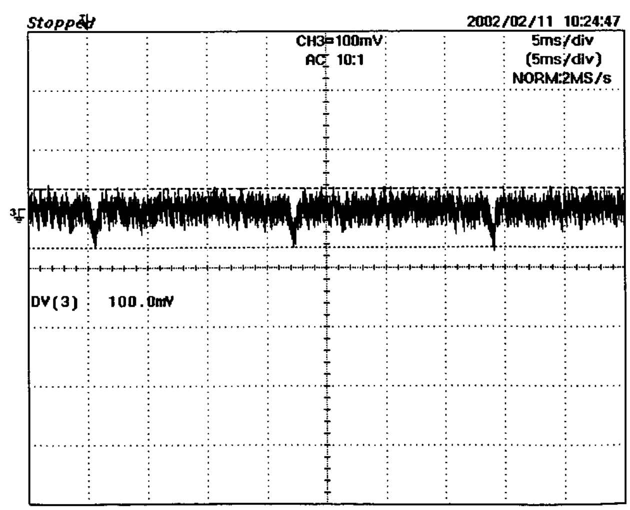
Output ripple 85 VAC, 120 Ω, 100 µF/130 mΩ



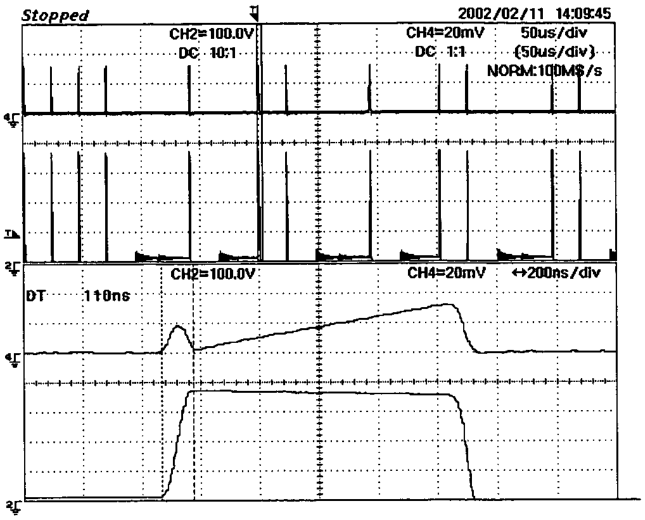
Output ripple 265 VAC, 120Ω, 100 µF/130mΩ



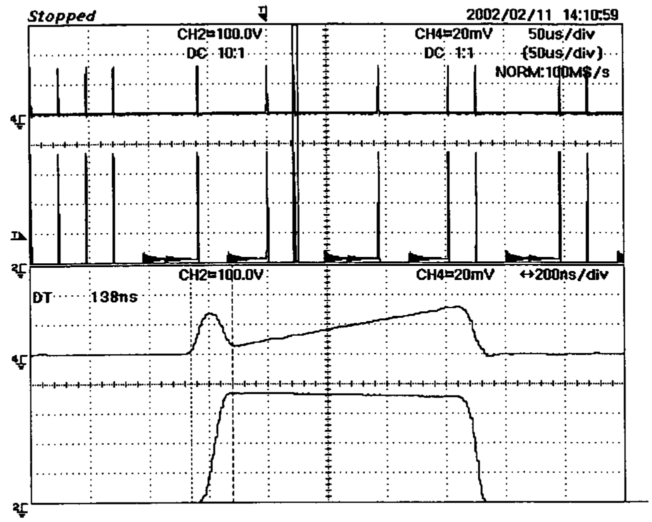
Output ripple 85 VAC, 120 Ω, 300 µF/ 43mΩ



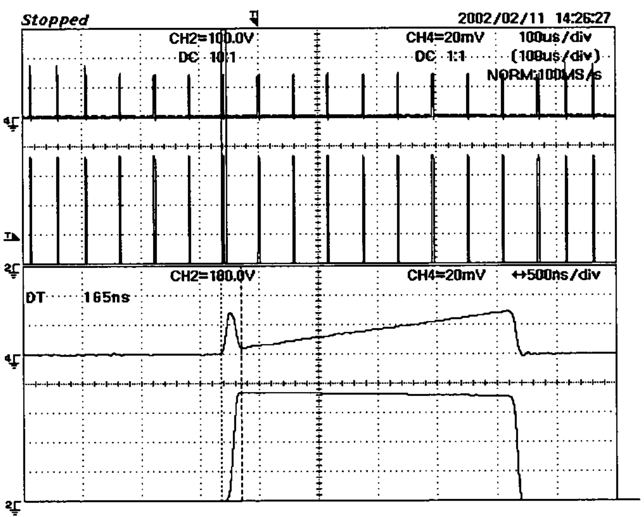
Output ripple 265 VAC, 120 Ω, 300 µF/43 mΩ



Drain current, 265 VAC, 1 mH, DCM pulse, 100 mA load current

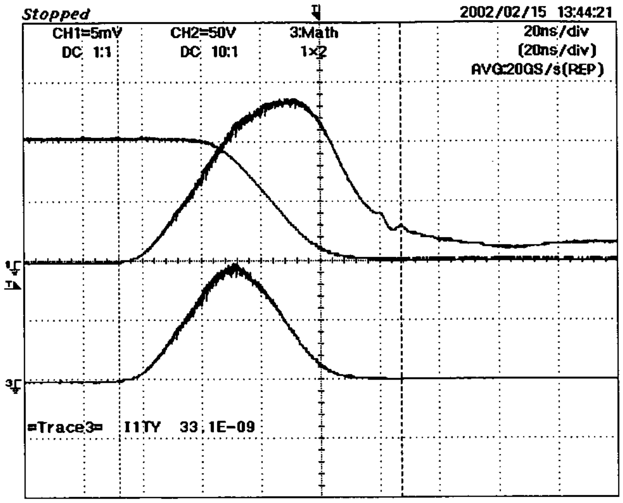


Drain current, 265 VAC, 1 mH, CCM pulse, 100 mA load current

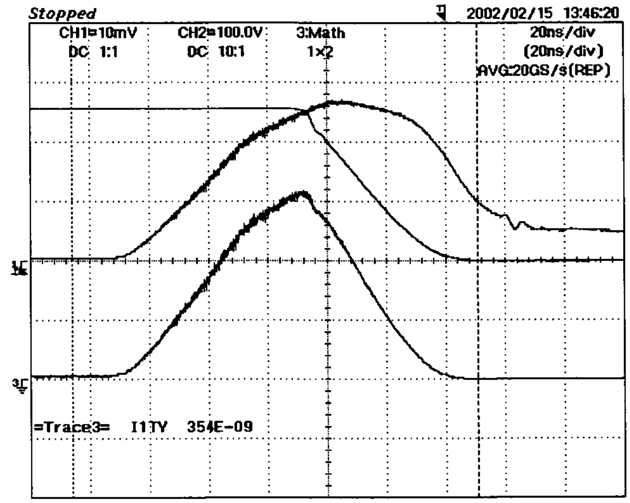


Drain current, 265 VAC, 3.25 mH, CCM pulse 175 mA load current

Note: With the 3.25 mH choke literally every switching cycle has been continuous ones. With the 1 mH choke the vast majority of switching cycles are discontinuous.



*Switching loss V_D * I_D with 10 mA / mV at turn-on at 85 VAC [33 nWs * 10 * 44 kHz = 15 mW]*



*Switching loss V_D * I_D with 10 mA / mV at turn-on at 265 VAC [354 nWs * 10 * 44 kHz = 156 mW]*

Based on the measured switching losses, the total losses in TNY254 are as follows

VIN [VDC]	90	375
Conduction loss [mW]	122	29
Switching loss [mW]	15	156
Drain supply dissipation [mW]	18	75
Total device dissipation [mW]	155	260

This estimate is based on the following assumptions:
- 48 Ω on resistance
- 44 kHz switching frequency
- 200 μA Drain supply current
- 250 mA current limit
- current probe delay in switching loss measurements neglectable

Regulation Type		On/Off	PWM
Die size		100%	127%
no of pins		4	3
package options		DIP-8, DIP-4, SOIC-8	DIP-8, DIP-4, D-PAK, SOT-223, SOIC-8
regulation	opto	2 components	n/a (*) (no local Bypass pin)
	comp. cost	$0.080	
	placement cost	$0.01	
	bootstrap	5 components	4 components
	comp. cost	$0.052	$0.06
	placement cost	$0.025	$0.02
minimum DC		0%	1.7%
maximum DC		67%	67%
buck-boost possible		yes with opto feedback	yes, but not with a simple circuit (*) (no local Bypass pin)
open control loop operation		yes (with Auto-restart -> resistor between EN and S, or between BP and S respectively)	no (Auto-restart)
open control loop protection		no	yes (Auto-restart)
short circuit protection		no (no Auto-restart)	yes (Auto-restart)
5V output		yes	not directly (Vc=5.7V)
audio noise?		yes, but very little like any SMPS depends on buck choke (saturation)	no
EcoSmart (<300mW)		<100mW @ 265V (TNY254, 1mA pre-load)	<100mW @ 265V) (LNK501 DC4DC, 1mA pre-load)
pre-load?		required (1-2mA) (depends on bootstrap cap)	required (depends on Control pin & bootstrap cap)
EMI		better (6-10dB) (?? Internal clock doubling)	worse
Usable in PLC communication apps?		yes with additional filters (constant frequency changes due to cycle skip.)	yes (question of fixed switching frequency)

(*) Local supply pin for analog control schemes such as PWM and PFM (variable off-time) was considered. However, current available from a Bypass pin is too limited to provide acceptable optocoupler bias current for analog feedback.

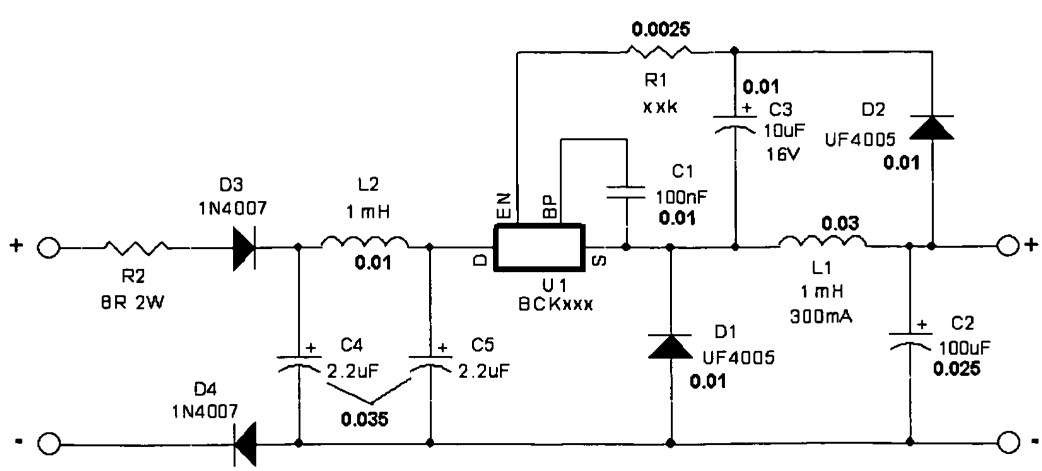
Appendix D – System Cost Analysis

The following table lists the replacement cost for *BuckSwitch*.

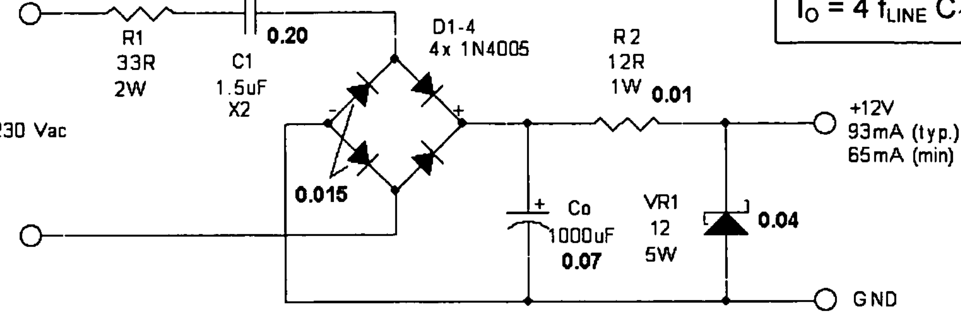
BuckSwitch vs. Integrated Solution				
Key Component	Cost of Key Component	Total additional component cost relative to BuckSwitch	Total Replacement Cost	Note
VIPer12	$0.30	$0.055-0.085	$0.355-0.385	Vo > 15 V
	$0.20	$0.055-0.085	$0.255-0.285	
	$0.30	$0.007-0.100	$0.370-0.400	Vo < 15 V
	$0.20	$0.070-0.100	$0.270-0.300	
	$0.30	$0.115-0.145	$0.415-0.445	Vo < 8V
	$0.20	$0.115-0.145	$0.325-0.345	
TEA1520	$0.30	$0.025	$0.325	
BuckSwitch vs. Cap Dropper with Bridge Rectifier				
Key Component	Cost of Key Component	Total additional component cost relative to BuckSwitch	Total Replacement Cost	Note
1.5 uF, X2	$0.20	$0.135	$0.335 - $0.145 $0.19	Io(max) = 65 mA extra required for BCKxx1
3.0 uF, X2	$0.30	$0.135	$0.435 - $0.145 $0.29	Io(max) = 130 mA extra required for BCKxx1
Note: Cap dropper only runs from European mains, has poor efficiency & no-load consumption, occupies larger PCB area, and cannot be produced in SMD.				

The analysis is based on the following circuits:

BuckSwitch vs Cap Dropper

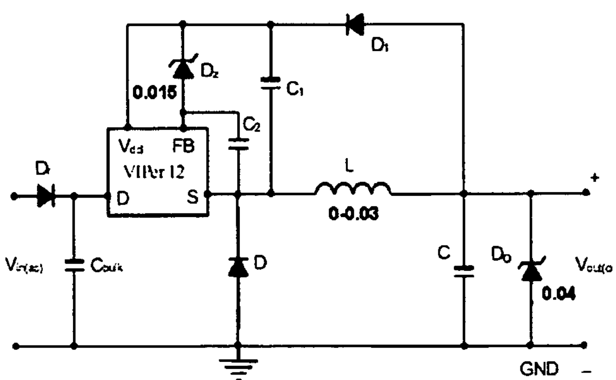


$I_O = 4\, f_{LINE}\, C_1 (\sqrt{2}\, V_{IN} - V_D - V_O)$

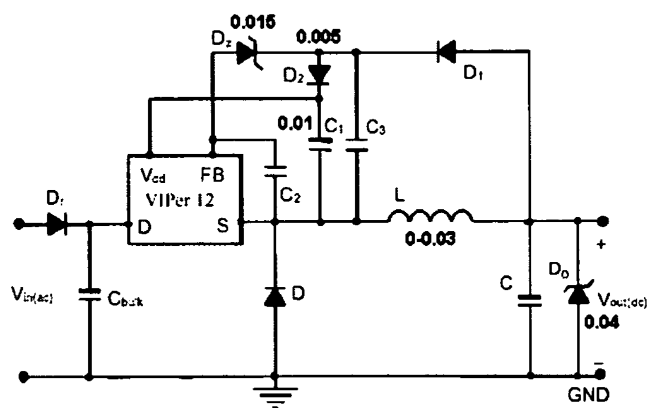


BuckSwitch vs Integrated Solutions

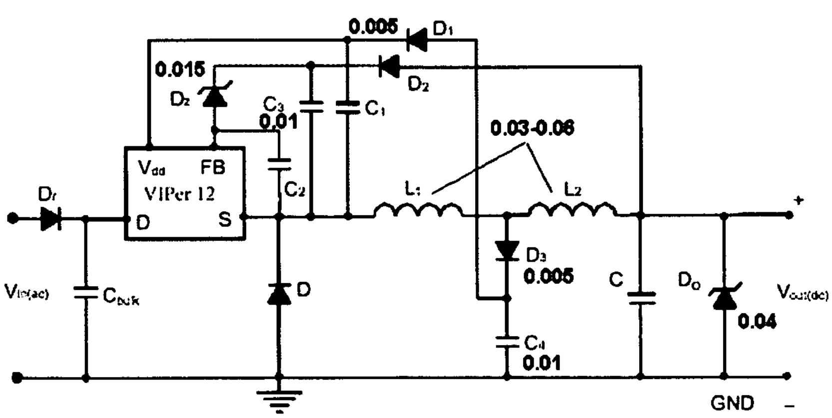
VIPer12



$V_O > 15$ V

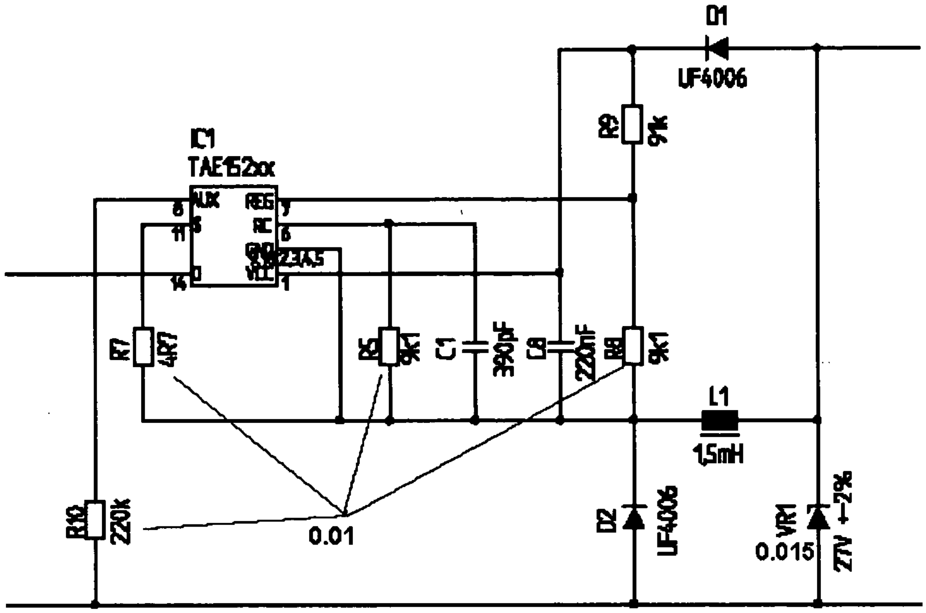


$V_O < 15$ V



$V_O < 8$ V

TEA1520 (STARplug)



Appendix E – Useful Equations

The minimum inductance to deliver a given output power in a buck converter running in MDCM is governed by:

$$L_{MIN\_PWR} = \frac{2 \cdot I_O \cdot V_o \cdot (V_{IN(MAX)} - V_{DS} - V_O)}{I^2_{LIM(MIN)} \cdot f_{OSC(MIN)} \cdot (V_{IN(MAX)} - V_{DS})} \quad (1)$$

However, to guarantee fully DCM the buck inductor has to be lower than the critical inductance:

$$L_{CRIT} = \frac{V_O - \frac{V_O^2}{V_{IN(MIN)} - V_{DS}}}{2 \cdot I_O \cdot f_{OSC(MAX)}} \quad (2)$$

With (1) and (2) the maximum output current for a buck converter in fully DCM can be calculated:

$$I_{O\_DCM(MAX)} = \frac{I_{LIMIT(MIN)}}{2} \sqrt{\frac{f_{OSC(MIN)} \cdot \left(1 - \frac{V_O}{V_{IN(MIN)} - V_{DS}}\right) \cdot (V_{IN(MAX)} - V_{DS})}{f_{OSC(MAX)} \cdot (V_{IN(MAX)} - V_{DS} - V_O)}} \quad (3)$$

To not violate the absolute maximum peak Drain current rating of the device the buck inductance has to be at least:

$$L_{MIN\_SOA} = \frac{V_{IN(MAX)}}{0.9 \cdot I_{DP(MAX)}} \cdot t_{ON(MIN)} \quad (4)$$

$V_{IN(MIN)}$	minimum DC bus voltage at Drain pin
$V_{IN(MAX)}$	maximum DC bus voltage at Drain pin
V_{DS}	Drain to Source voltage
$f_{OSC(MIN)}$	minimum switching frequency
$f_{OSC(MAX)}$	maximum switching frequency
$I_{DP(MAX)}$	absolute maximum peak Drain current rating at 400 V
$t_{ON(MIN)}$	maximum minimum on time (i.e. $t_{LEB(MAX)} + t_{ILD(MAX)}$)

Based on an input voltage range of 90-375 VDC, a minimum and maximum switching frequency of 62 kHz and 70 kHz, respectively, and equations (1), (2), and (3) the maximum output current in a discontinuous buck converter depending on the output voltage can be calculated:

Vo [V]	3.3	5	12	15	24	40	75
Io [mA]	116	115	110	108	102	88	33
Po [W]	0.38	0.58	1.32	1.62	2.45	3.52	2.48
Lmin [uH]	195	292	660	804	1178	1620	1015
Lcrit [uH]	195	292	660	804	1178	1620	1015

It has to be noted, that according to (4) the minimum inductance required to stay below the peak drain current rating of BCKxx1 is 300 µH (assuming a peak drain current rating of 500 mA at 400 V and $t_{LEB(MAX)} + t_{ILD(MAX)}$ = 360 ns). This will lead to smaller DCM output currents for the 3.3 V and 5 V as shown in the table above allowing a greater L_{CRIT} value.

BuckSwitch Introduction

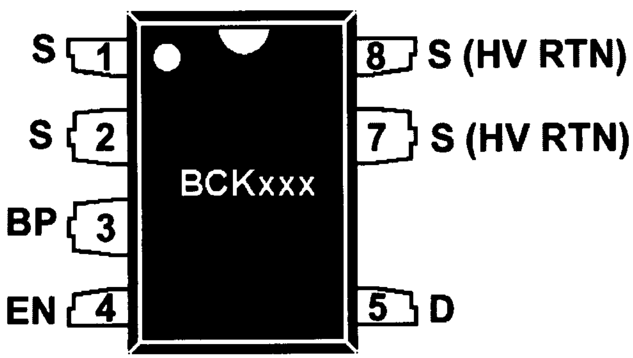
13-Nov-02

BuckSwitch at a Glance

- **Competing with non-isolated low output current passive power supplies**
  - Capacitive dropper
  - Linear
- **Preferred topology: buck or buck-boost**
  - Flyback possible too (in both, high or low side position)
- **On/Off control similar to *TinySwitch***
  - Inverted ENABLE pin logic
  - Switching is disabled when current into EN pin exceeds 49 μA

Target Output Current Range & Package

Device Type	Min. Current Limit (T_J=100 ºC, 60 mA/µs)	$R_{DS(ON)}$ (max @ T_J=25 ºC)	Target MDCM Output Current Capability
BCKxx1	240 mA	32 Ω	120 mA
BCKxx2	350 mA	16 Ω	175 mA
BCKxx3	450 mA	9 Ω	225 mA

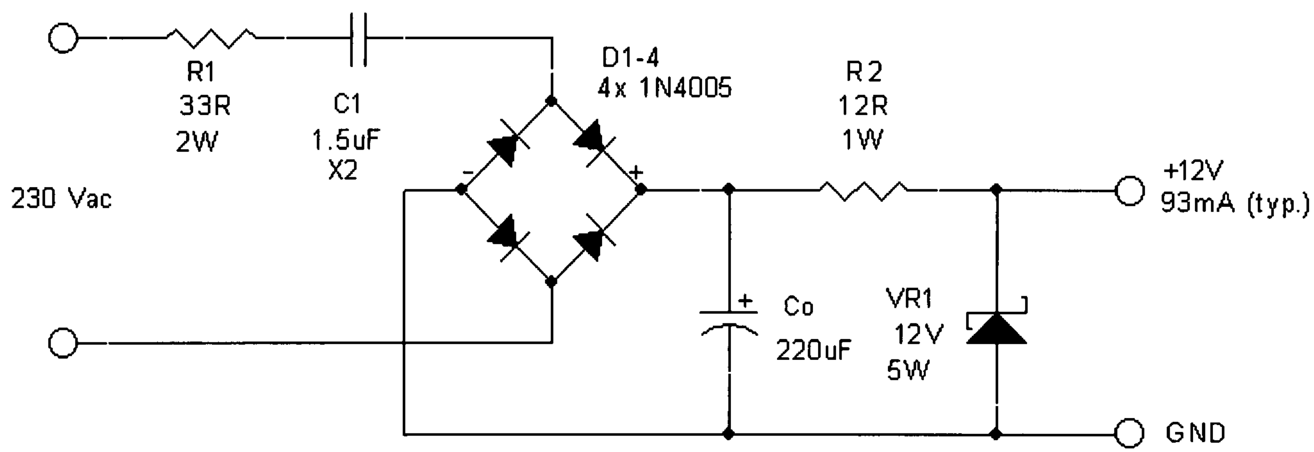


BP .... Bypass/V_{CC}
S .... Source (including HV return)
EN .... Enable
D .... Drain

BuckSwitch System Level Benefits compared to Passive Solutions

- **Universal input voltage range**
- **Higher efficiency than passive solutions**
- **Open control loop protection (auto-restart)**
- **Low no-load input power**
  - Target is < 100 mW @ 265 VAC
- **Higher power factor**
  - Cap droppers suffer from very low power factor

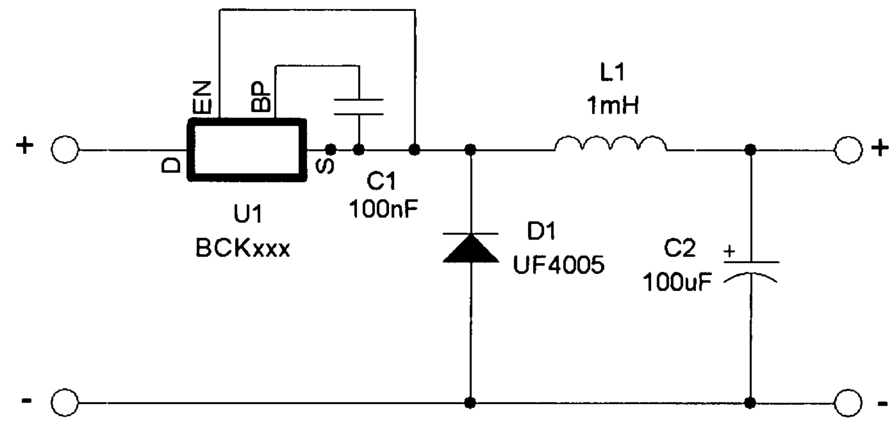
Cap Dropper Circuit Example

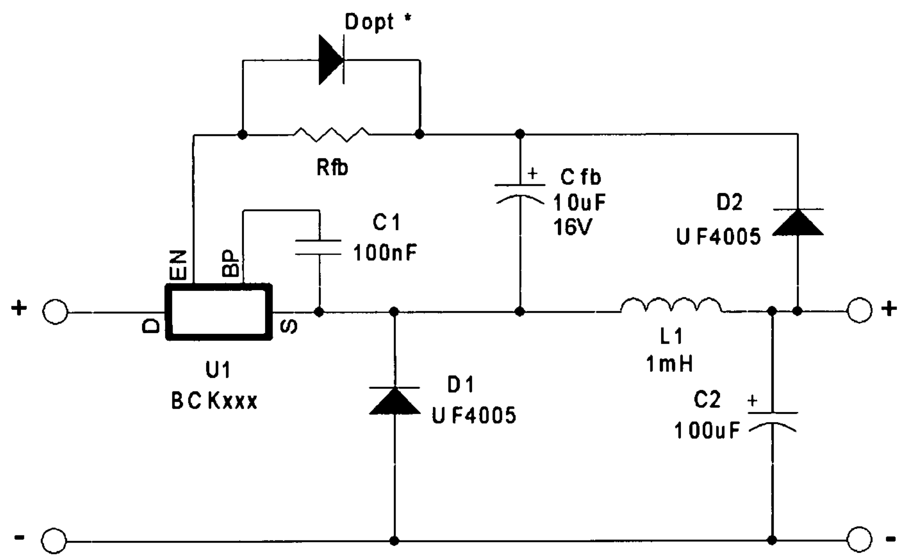


- Additionally required components include MOV (line surge protection), bleeder resistor for C1, and load protection zener
- Typical performance

BuckSwitch Circuit Examples (1)

Open-loop buck (auto-restart disabled)

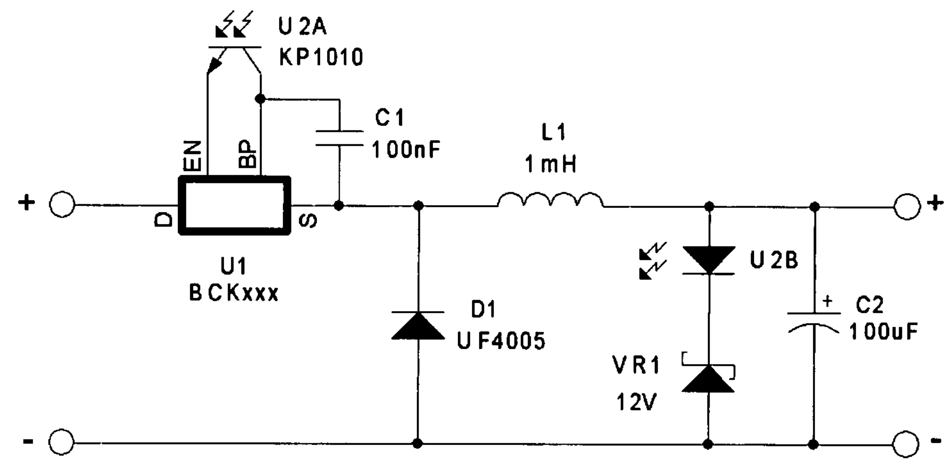


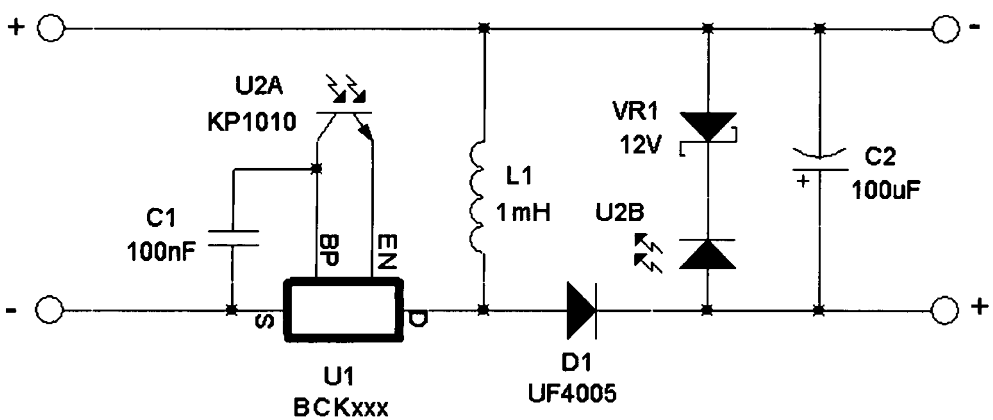


Bootstrap controlled buck (auto-restart optionally disabled during start-up)

BuckSwitch Circuit Examples Cont.

Optocoupler controlled buck





Optocoupler controlled Buck-Boost

www.powerint.com

Key Features

- **Internal 6.3 V zener at BYPASS pin**
  - External supply in high ambient temperature applications
- **BYPASS pin used to source external circuitry**
  - Minimum Enable turn-off threshold current should be deliverable
  - Local supply allows optocoupler feedback (buck-boost)
  - Minimum 53 μA
- **Auto-restart can be disabled by shorting Enable to Source**
  - Open-loop buck converter
  - Startup into big capacitive load
  - Useful during device testing

Key Electrical Specifications

Parameter	Note		Min	Typ	Max	Units
Output Frequency			62	66	70	kHz
Maximum Duty Cycle			66	68	71	%
ENABLE Pin Turnoff Threshold Current			45.5	49	52.5	μA
ENABLE Pin Voltage			1.55	1.70	1.85	V
DRAIN Supply Current	MOSFET not switching				250	μA
Current Limit	75 mA/μs	BCKxx1	240	257	275	mA
	500 mA/μs		TBD	308	TBD	
	75 mA/μs	BCKxx2	350	375	401	
	500 mA/μs		TBD	450	TBD	
	75 mA/μs	BCKxx3	450	482	515	
	500 mA/μs		TBD	578	TBD	
Thermal Shutdown Temperature			TBD		TBD	°C
ON-State Resistance	BCKxx1 (T_J=+25 °C)			28	32	Ω
	BCKxx2 (T_J=+25 °C)			14	16	
	BCKxx3 (T_J=+25 °C)			7.8	9.0	
Breakdown Voltage			700			V
Auto-Restart ON-Time				50		ms
Auto-Restart Duty Cycle				6.25		%

From: Mike Matthews [mike.matthews@powerint.com]

Sent: Wednesday, April 02, 2003 8:06 AM

To: Stefan Baeurle

Subject: BuckSwitch Eval

Stefan
While I'm away, as discussed yesterday, I would suggest making sure you can understand along with Kent and Art, the issues with BuckSwitch.

As you have time in order of priority, I would then suggest the following:

1. the Link type configuration
Starting with just the DAK16 as is to start with adjusted feedback resistor (the by way, it is probably possible to feed the bypass pin separately form the clamp capacitor also in this configuration to maybe help reduce the problems seen in the buck converter configuration)

Then looking at the I core choke to find Al value and saturation - it may be that the energy stroage possible will limit this to a 1.5W type trickle charger but that will also be OK.

See if it is possible to use ferrite loaded epoxy to dip the core and the effect on the Al value/saturation characteristic

Finally, VI characteristic and efficiency/no-load and EMI performance

2. Link reduced version - Balu's idea of just a resistor - as above

3. CC output buck configuration

in parallel, the costing support is still important so updating the Samsung costings as data comes in and feeding this to Andy and Bruce. Apart from this I would suggest all costing comes second to the above work.

There's probably about a month work here!
Hope the above makes sense.

Rgds
Mike

Facsimile Cover Sheet

Power Integrations, Inc.
5245 Hellyer Avenue
San Jose, CA 95138-1002 USA

Date:	Number of Attached Pages:
24 June 2003	11

To:

Fax Number: (206) 292-8606

James Go
Blakely, Sokoloff, Taylor & Zafman LLP
Two Union Square, Suite 3000
601 Union Street
Seattle, WA 98101-1365

Phone: (206) 292-8600 Ext. 310

Subject: Figures for Simple Energy Transfer Element

Message:

Attached are figures for the document that Mike Matthews sent to you this morning.

Best Regards,

William M. Polivka
Phone: (408) 414-9629
Fax: (408) 414-9729
E-Mail: wpolivka@powerint.com

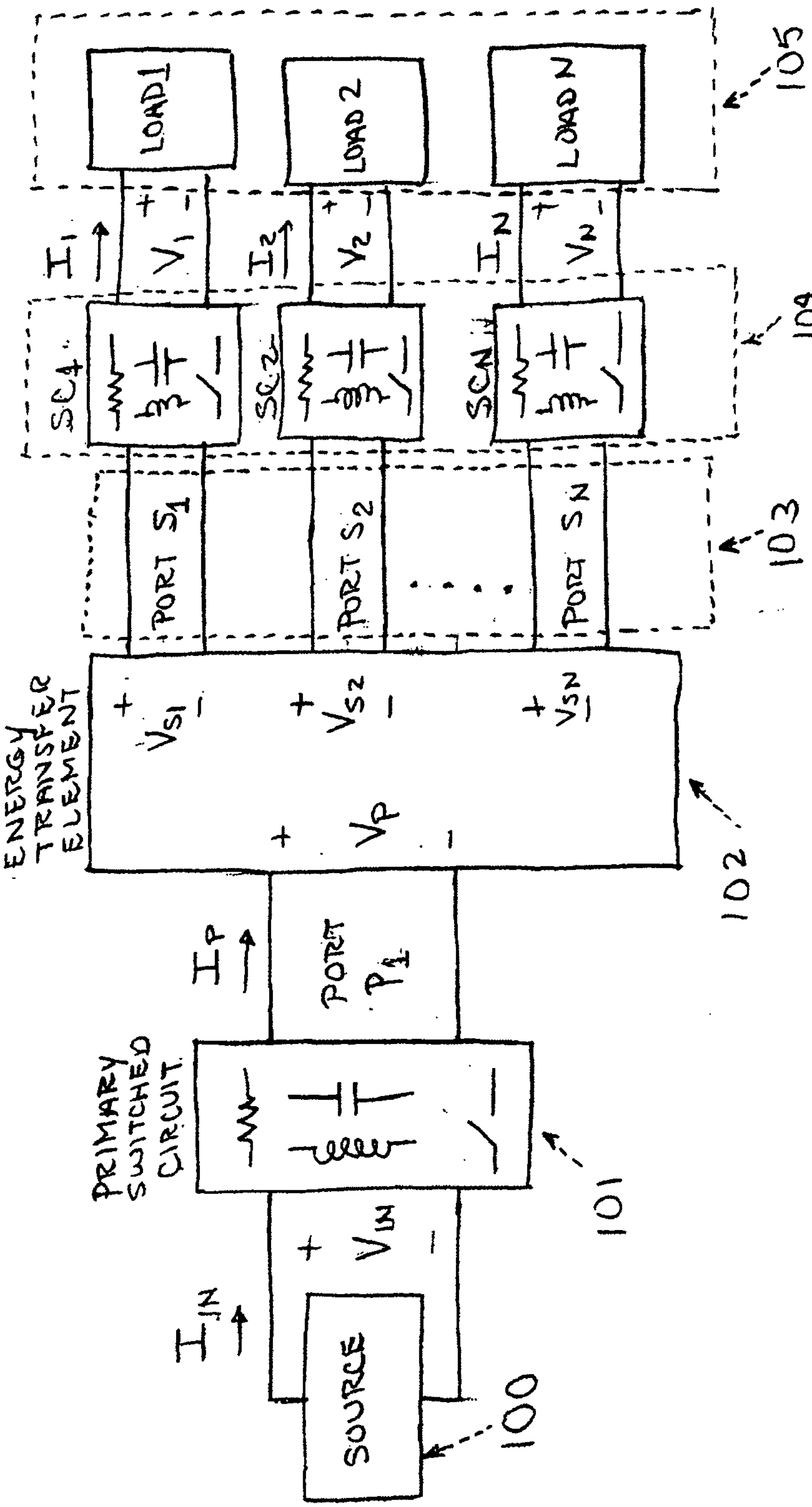

SOURCE
100
I_{IN}
+ V_{IN} -
PRIMARY SWITCHED CIRCUIT
101
I_P
PORT P_1
ENERGY TRANSFER ELEMENT
+ V_P -
102
+ V_{S1} -
+ V_{S2} -
+ V_{SN} -
PORT S_1
PORT S_2
PORT S_N
103
SC_1
SC_2
SC_N
104
I_1
+ V_1 -
I_2
+ V_2 -
I_N
+ V_N -
LOAD 1
LOAD 2
LOAD N
105

FIGURE 1

PRIOR ART

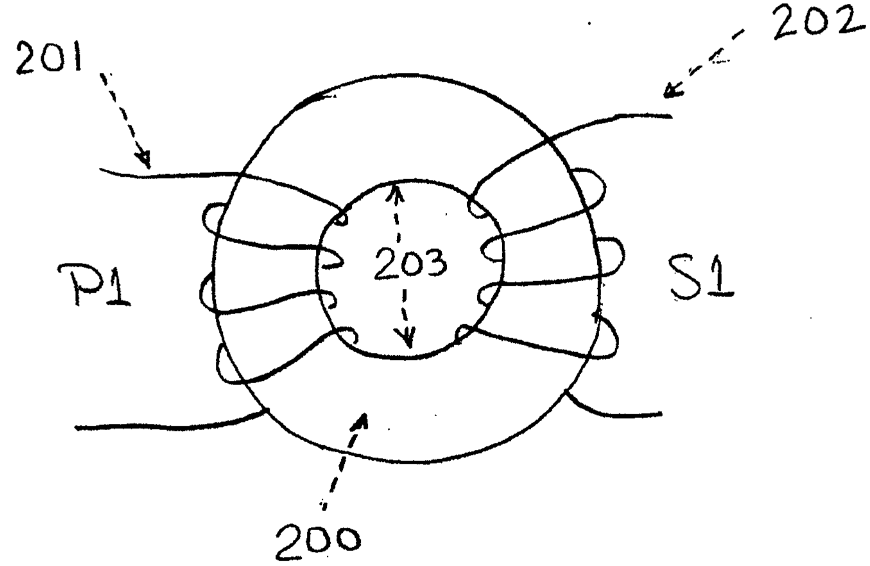


FIGURE 2

PRIOR ART

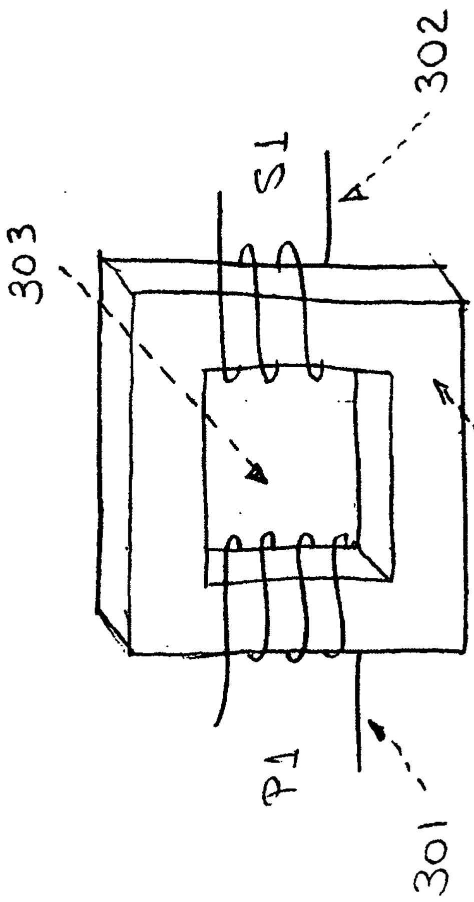


FIGURE 3

PRIOR ART

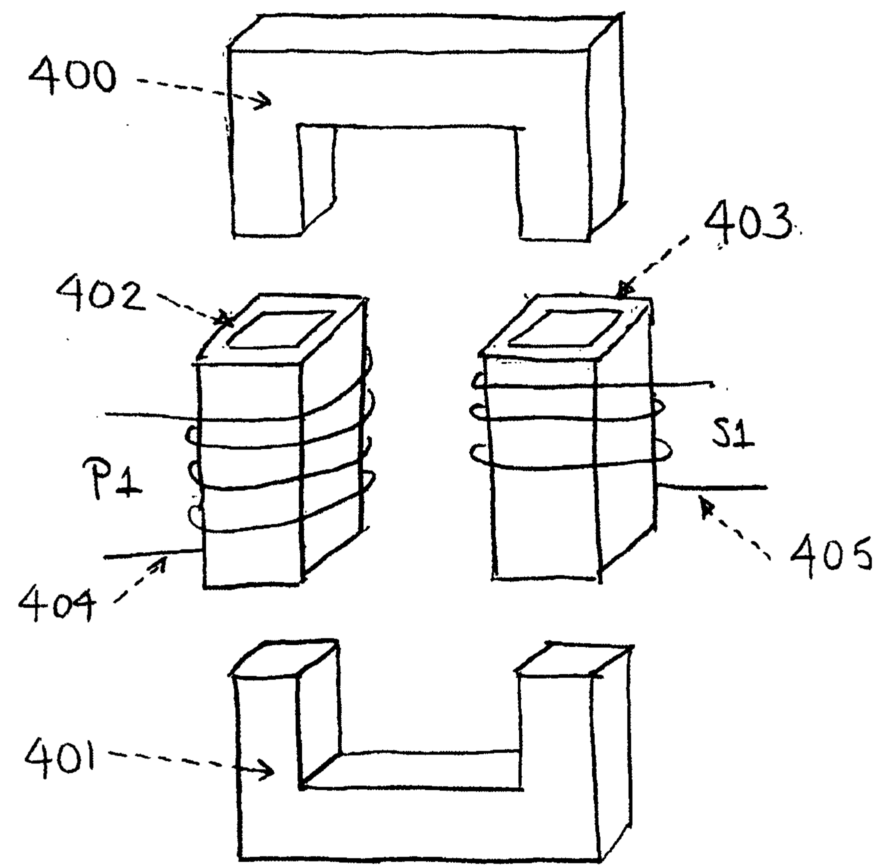


FIGURE 4

PRIOR ART

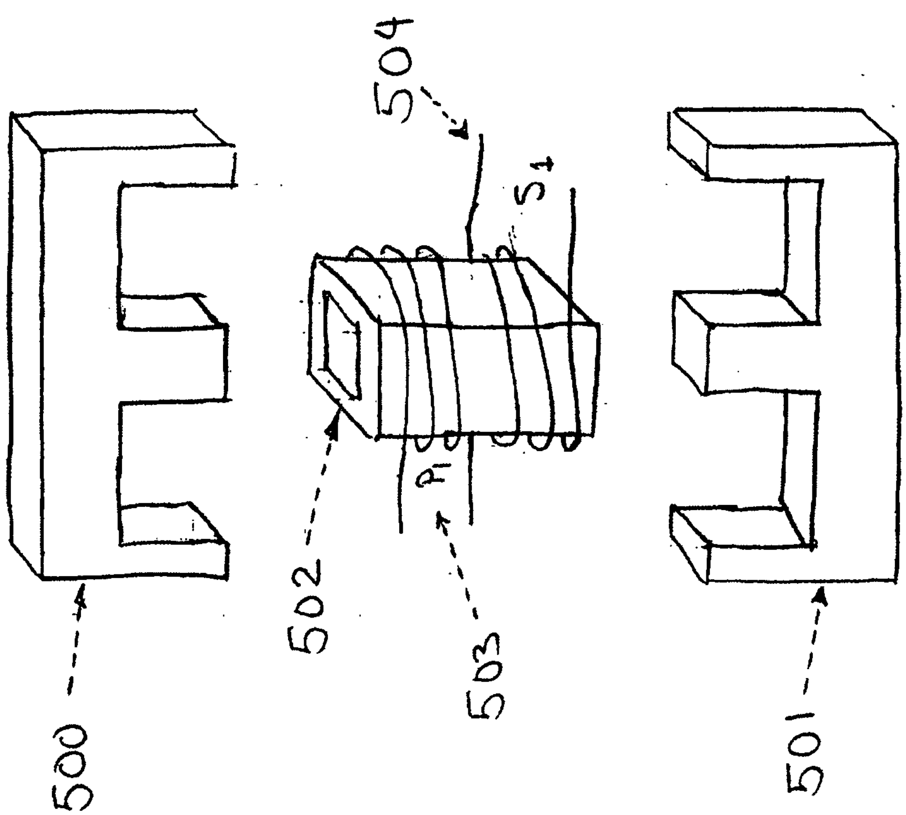


FIGURE 5

PRIOR ART

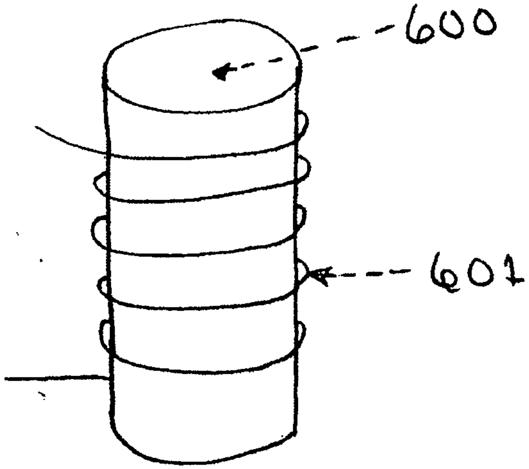


FIGURE 6

PRIOR ART

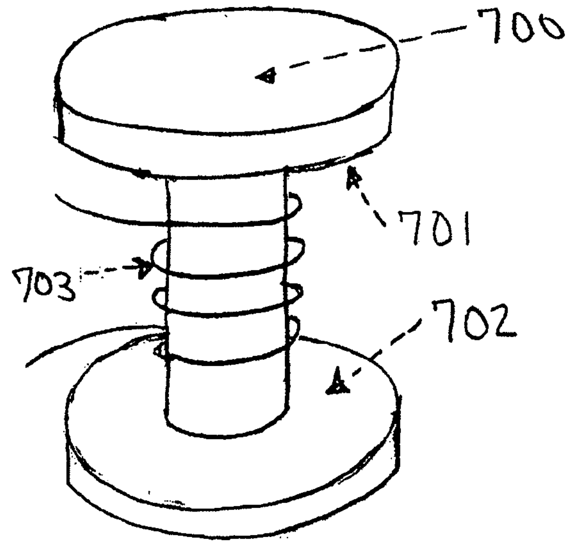


FIGURE 7

PRIOR ART

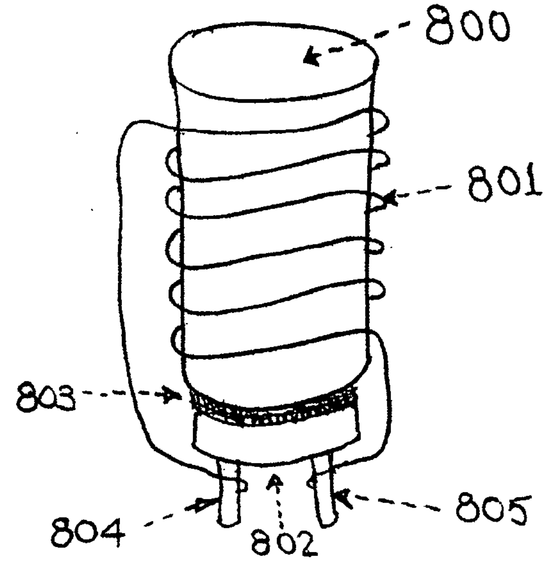


FIGURE 8

PRIOR ART

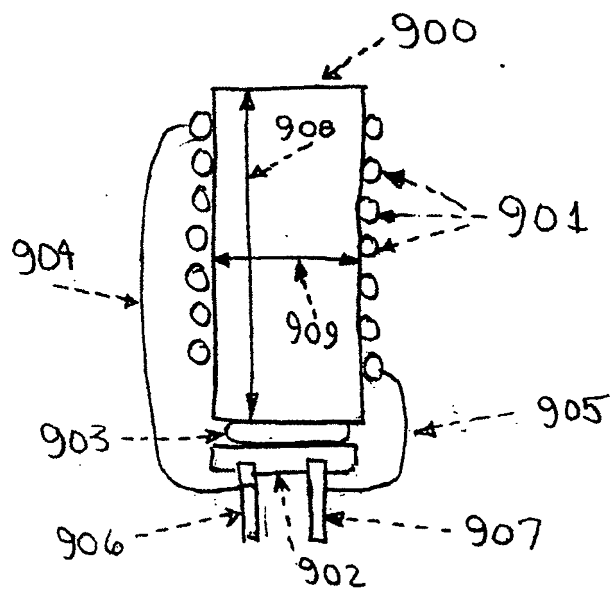


FIGURE 9

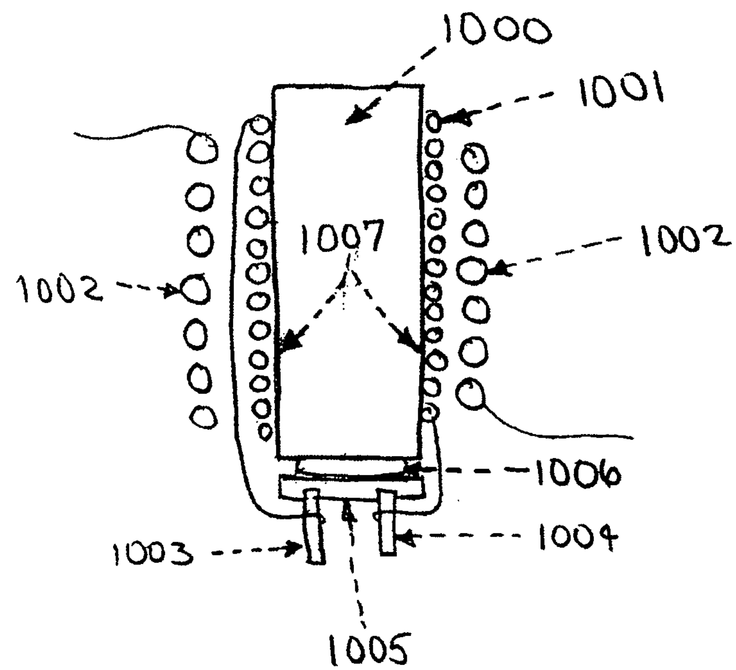


FIGURE 10

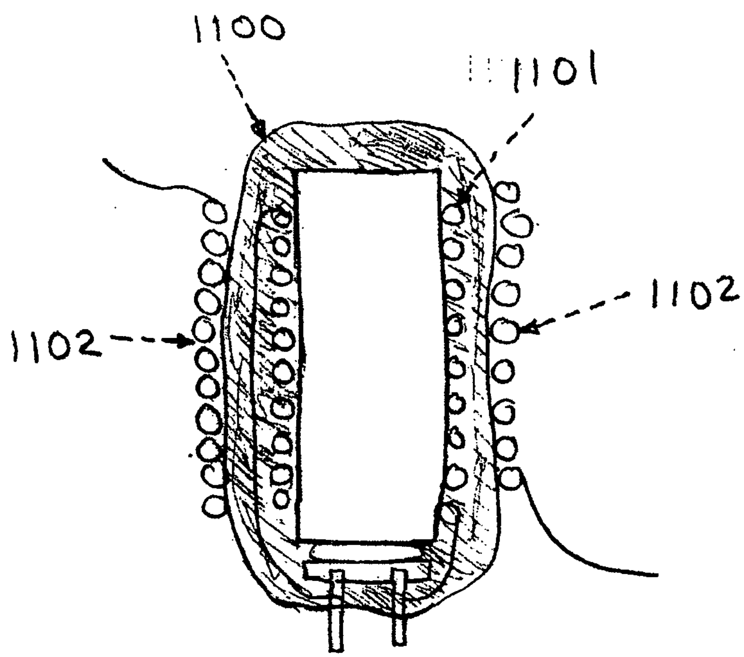


FIGURE 11

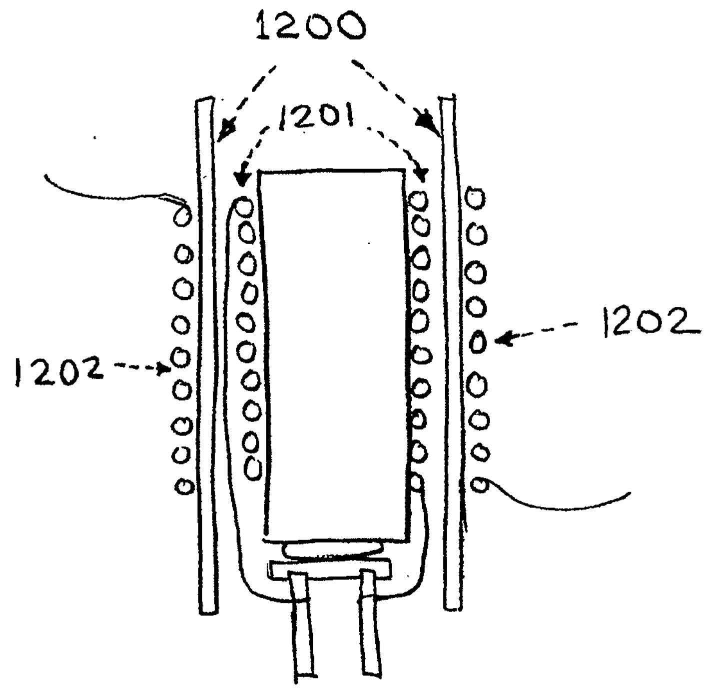


FIGURE 12

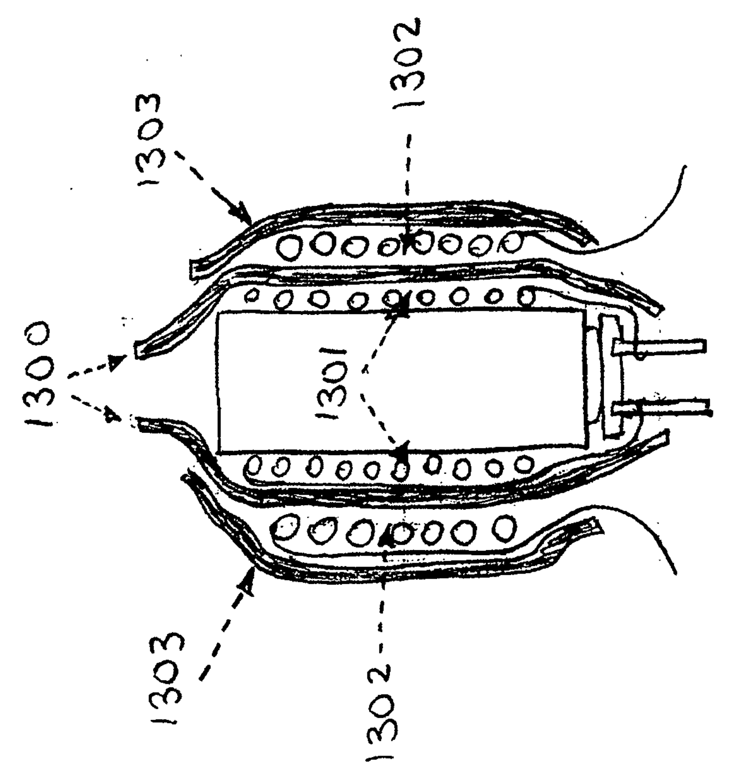


FIGURE 13

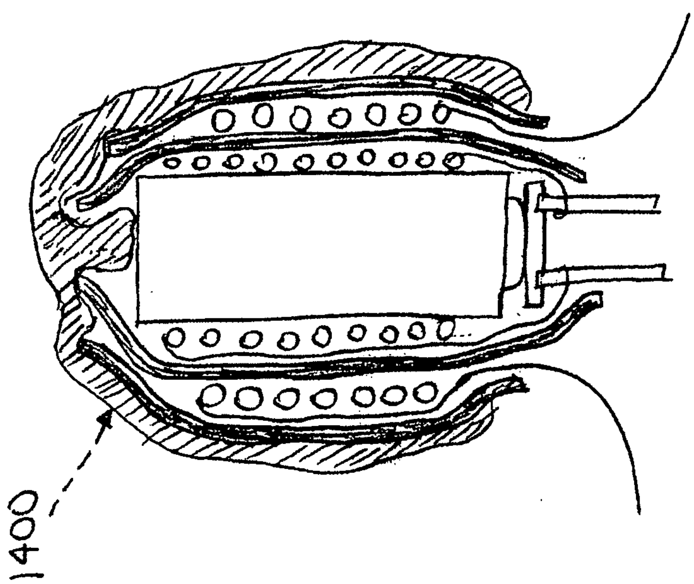
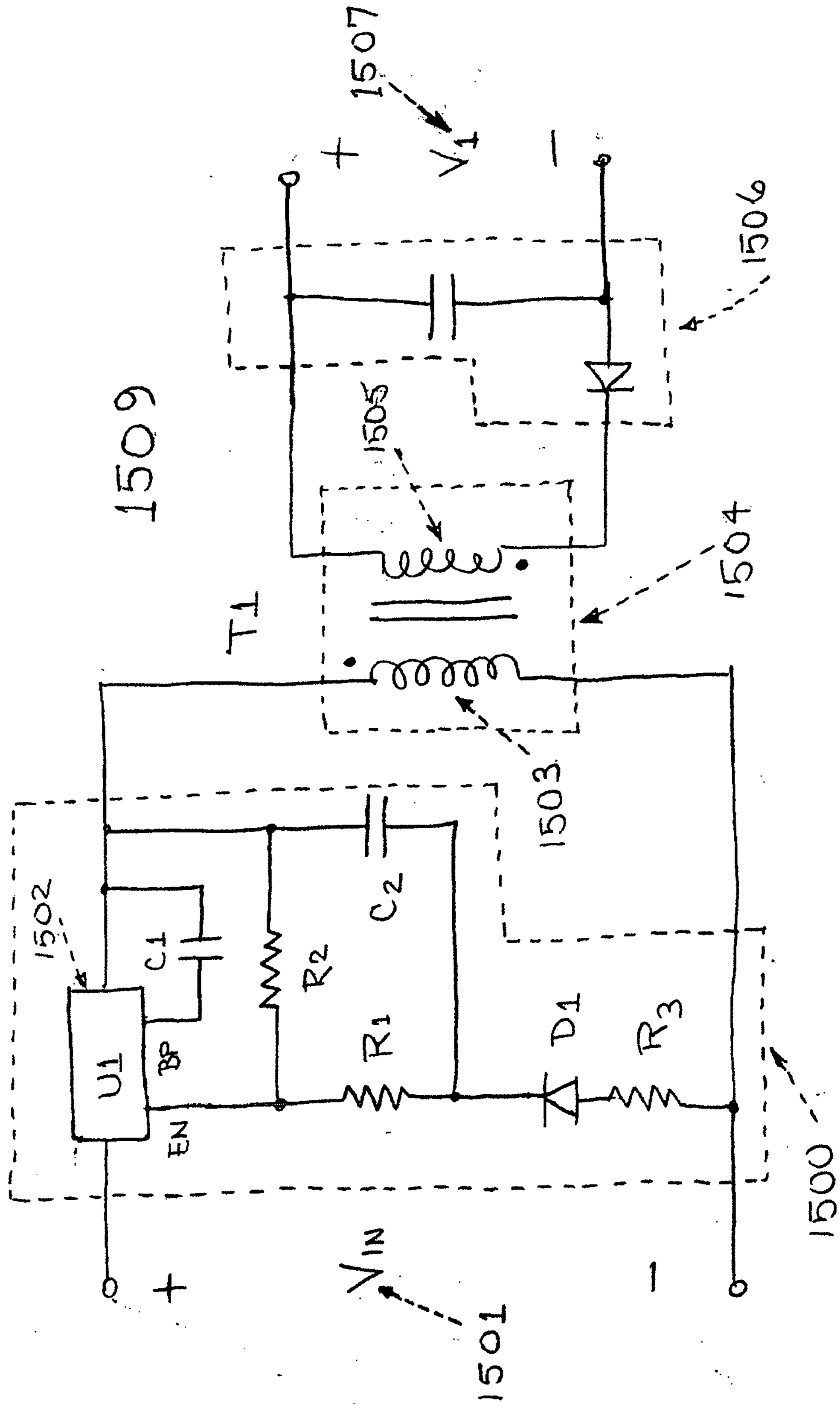


FIGURE 14



1509
1507
+
V_1
−
1506
1505
1504
T1
1503
1502
C_1
U1
BP
EN
R_2
C_2
R_1
D_1
R_3
1500
+
V_{IN}
−
1501

FIGURE 15

SIMPLE ENERGY TRANSFER ELEMENT FOR POWER CONVERTERS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to magnetic devices, and more specifically, the present invention relates to components that transfer energy in power converters. It involves a method of construction that reduces the cost of inductors and transformers that have more than one winding.

Background Information

Most modern electronic equipment requires a regulated source of DC voltage to operate. The magnitude of the regulated voltage is typically less than 20 volts. Often the regulated DC voltage must be obtained from an unregulated source of DC or AC voltage that has a magnitude several times greater than the desired regulated value. It is the purpose of electronic power supplies to provide the regulated voltage from the unregulated source.

Two separate and distinct functions are inherent in an electronic power supply. One is the function of power conversion, performed by a power converter. The other is the function of regulation, performed by a control mechanism acting on the power converter. The typical electronic power converter uses a connection of switches, energy storage elements and energy transfer elements to change the magnitude of one voltage or current to a different magnitude of voltage or current. The control mechanism senses the voltage or current to be regulated, compares the magnitude of the sensed voltage or

current to the desired magnitude, and then adjusts the operation of the power converter in a way to reduce the error between the sensed voltage and the desired magnitude.

Energy transfer elements in power converters are almost exclusively magnetic devices that comprise a magnetic element with two or more windings. A magnetic element is any structure that has a magnetic permeability substantially greater than free space. A winding is an electrical conductor that couples magnetic flux. The following explanation of Figure 1 defines the role of the energy transfer element in a modern power converter, and establishes the meaning of several terms that will be useful in the detailed description of the invention.

An unregulated source 100 is coupled to a primary switched circuit 101 that contains one or more electrical components and switches. A switch is any component that can change its state of conduction between a first state that allows the conduction of electrical current and a second state that blocks conduction of electrical current. Switches can be mechanical components or electrical components. The switches may operate actively under external control or they can operate passively in response to the voltages that appear across them or the currents that pass through them. Primary switched circuit 101 is coupled to the electrical port P_1 of energy transfer element 102. An electrical port is a pair of electrical conductors where energy may be supplied or withdrawn. An energy transfer element is a device with at least two electrical ports that allows energy to pass from one port to another port. The energy transfer element 102 receives energy at its primary port P_1 from primary switched circuit 101. The energy received at primary port P_1 is transferred to one or more secondary ports 103. Secondary ports are shown in

general as S_1 through S_N in Figure 1. The secondary ports 103 deliver energy to one or more secondary switched circuits 104. Each secondary port delivers energy to a secondary switched circuit that contains one or more electrical components and switches. The secondary switched circuits in Figure 1 are designated SC_1 through SC_N. The secondary switched circuits 104 are coupled to one or more loads 105. Each secondary switched circuit is coupled to a load. The relationship between the voltage at the loads 105 and the voltage at the source 100 is determined by the design of the primary switched circuit 101, the energy transfer element 102 and the secondary switched circuits 104. To make a regulated power supply from the power converter, one skilled in the art would apply a circuit or other mechanism to adjust the operation of the switched circuits to maintain a desired voltage or current at one or more of the loads. The adjustments may be made to either the primary switched circuit 101, the secondary switched circuits 104, or to both 101 and 104.

Magnetic devices with two or more windings can be used for purposes other than energy transfer elements in power converters. Two other uses are energy storage elements and switches. Some power converters use magnetic devices with two or more windings as energy storage elements and as switches in addition to energy transfer elements. It will be obvious to one skilled in the art that the methods of construction described herein for energy transfer elements in power converters apply to magnetic devices that are used for energy storage elements.

Advances in technology permit reductions in physical size, power consumption, and cost of electronic devices. One skilled in the art will recognize that the use of a

simple energy transfer element can reduce the cost of power supplies for low power electronic equipment.

Figure 2 shows an example of a common construction for an energy transfer element that is a magnetic device. It comprises a magnetic element 200, a primary winding 201 that forms a primary port P1, and a secondary winding 202 that forms a secondary port S1.

The two-dimensional drawing in Figure 2 shows that the structure of the magnetic element 200 is a torus. The shape of the cross section of the torus in the third dimension is not relevant to this description.

Figure 2 shows two windings that are shown for clarity of illustration. One skilled in the art will recognize that the structure is not limited to two windings. Windings 201 and 202 are also shown at opposite sides of the magnetic element 200 for clarity. One skilled in the art will recognize that the windings may occupy any position on the magnetic element, and that multiple windings may cover the same area of the magnetic element. It is in fact desirable in most power converters that windings be as close together as possible to improve magnetic coupling.

The important characteristic of the toroidal structure is that the magnetic element defines a closed circle that completely surrounds every turn of every winding. As a consequence of this closed circular construction, one end of each of the windings 201 and 202 must pass through the hole defined by the inner diameter 203 of the structure. This restriction complicates the manufacturing process. The curved surface of magnetic

element 200 is an additional complication to the application of windings. Manufacturing becomes increasingly difficult and more costly as the inner diameter 203 gets smaller.

Figure 3 is a modification to the toroidal structure of the magnetic element 200 in Figure 2. The structure of the magnetic element 300 in Figure 3 is a closed construction like magnetic element 200. The major difference between magnetic element 300 and magnetic element 200 is that magnetic element 300 has sections that are defined by straight lines, whereas the geometry of magnetic element 200 is curved. The closed rectangular structure of magnetic element 300 has the same fundamental problems with manufacturability and high cost as the closed circular structure of magnetic element 200. One end of windings 301 and 302 must pass through the inner rectangular area 303.

The problem of manufacturability is generally addressed by the technique illustrated in Figure 4. The closed structure of the magnet element 300 of Figure 3 has been separated into the two pieces 400 and 401 having open structures in Figure 4. Additionally, two tubes 402 and 403 of a rigid nonmagnetic material that is also an electrical insulator are introduced to hold the windings 404 and 405. One familiar with the construction of magnetic components for power converters will recognize 402 and 403 as bobbins. A bobbin is a rigid structure of an electrically insulating nonmagnetic material that holds windings for a magnetic element, to provide mechanical support and to maintain the relative positions of the windings when the magnetic element is absent. One familiar with bobbins for magnetic elements will know that bobbins typically contain conductive pins that terminate the ends of the windings, but are not necessary to realize the main advantages of the technique illustrated in Figure 4.

Figure 5 shows a variation of the technique of Figure 4 that is functionally equivalent to the construction of Figure 5. Figure 5 shows two magnetic elements 500 and 501 having open structures with a single bobbin 502 that holds two windings 503 and 504. When the three pieces 500, 501 and 502 are assembled, they will form a magnetic device with three legs that has two windings on the bobbin that surrounds the center leg.

The technique of constructing a magnetic device that has a closed structure from multiple elements that have open structures, shown by example in Figure 4 and Figure 5, removes the restriction that requires the ends of the windings to pass through an opening in a closed structure such as those in Figure 2 and Figure 3. However, this benefit to manufacturing is often defeated by the additional cost of the bobbins.

Figure 6 shows a magnetic element 600 the geometry of which is a a cylinder with one winding 601. The winding 601 is applied directly to the surface of the magnetic element 600 without a bobbin. Open structures similar to magnetic element 600 are common in the construction of magnetic energy storage elements that use only one winding. Many variants of the open structure are possible. Figure 7 shows a magnetic element 700 with regions 701 and 702 that deviate from the simple cylinder 600. One skilled in the art will see that structures of greater complexity may be desirable to assist in the manufacturing process or to control the.path of magnetic flux. The common feature of all such structural variations is that they have a region to accommodate a winding 703 without a bobbin.

One with ordinary skills in the art will also recognize that it is a common practice to apply a coating to the surface of magnetic elements. The coating maybe used for

example to protect the surface of the magnetic element and to protect the insulation on the winding from abrasion or for other purposes. Coatings on the surface of the magnetic elements are for the purposes of this disclosure considered to be an integral part of the magnetic element. Windings in contact with the coating are considered to be directly in contact with the magnetic element.

The absence of a bobbin does not preclude the use of conductive pins to terminate the ends of the winding. Figure 8 shows a magnetic element 800 with an open structure that holds a winding 801 without a bobbin. An electrical insulator 802 is attached to the magnetic element 800 with a suitable adhesive 803. The electrical insulator 802 holds two conductive pins 804 and 805. One end of winding 801 is coupled to the pin 804. The other end of winding 801 is coupled to the pin 805.

One with ordinary skill in the art will recognize that conductive pins can be mounted in many different ways on the magnetic element and at different locations on the magnetic element. Figure 8 shows two conductive pins at one end of the magnetic element as an example of what is commonly known as a radial lead style. An alternative construction is to put one pin at each end of the magnetic element, each pin collinear with the axis of the cylinder. The alternative style is commonly known as an axial lead style. Conductive pins in either style can be attached without the use of a separate insulator. It is common practice to use an insulating adhesive to attach conductive pins to magnetic elements.

It is useful for purposes of explanation and illustration to draw magnetic devices in the pseudo cross-section style of Figure 9. Figure 9 is a pseudo cross-section

representation of the device of Figure 8. The magnetic element 900 holds the coils of winding 801 in Figure 8. Winding 801 that is adjacent to the magnetic element 800 is represented by small circles 901. The electrical insulator 902 is attached to the magnetic element 900 by adhesive 903. The insulator 902 holds conductive pins 906 and 907. The wire that is part of winding 901 but not immediately adjacent to the surface of magnetic element 900 is represented by the thin lines 904 and 905. One end of winding 901 is coupled to the conductive pin 906. The other end of winding 901 is coupled to the conductive pin 907. Figure 9 shows two dimensions, 908 that is the length of the cylinder and dimension 909 that is the width of the cylinder. It is appreciated that in certain magnetic elements, the width 909 can vary along the length 908 of the magnetic element 900.

<u>SUMMARY OF THE INVENTION</u>

A method to construct an energy transfer element with two or more windings is disclosed. The simple construction achieves low cost of manufacture through the use of a magnetic element with an open structure and the absence of a bobbin. The simple energy transfer elements reduce the cost of small power supplies that deliver low output power.

In one embodiment, a first winding of ordinary magnet wire is wound on a magnetic element without a bobbin. A second winding of triple insulated wire is then wound directly over the first winding. The triple insulated wire allows the construction to meet the electrical isolation requirements of safety agencies.

In another embodiment, a first winding of ordinary magnet wire is wound on a magnetic element without a bobbin. The first winding is covered or encapsulated with an

insulating coating. A second winding of ordinary magnet wire is wound directly over the encapsulation or insulating coating of the first winding. The encapsulation or the insulating coating allows the construction to meet the electrical isolation requirements of safety agencies, sparing the added expense of triple insulated wire.

In another embodiment, a first winding of ordinary magnet wire is wound on a magnetic element without a bobbin. A sleeve of insulating material is placed over the first winding. A second winding of ordinary magnet wire is wound directly on the sleeve that covers the first winding.

In another embodiment, a first winding of ordinary magnet wire is wound on a magnetic element without a bobbin. A sleeve of insulating material is placed over the first winding. The sleeve of insulating material has the property that it shrinks when heated. Application of appropriate heating causes the insulating sleeve to conform to the contours of the first winding and the surface of the magnetic element. A second winding of ordinary magnet wire is wound directly on the sleeve that covers the first winding. An additional sleeve of insulation is optionally applied to protect the second winding or to take a third winding. The technique can be extended to accommodate any number of sleeves and windings.

Power converters for high power typically do not use magnetic elements with open structures. The open structures allow magnetic flux from the windings to couple to circuits in ways that are usually unpredictable and undesirable. Hence, power converters for high power typically use magnetic elements with closed magnetic structures. The closed structures substantially confine the magnetic flux to reduce the likelihood of

undesirable coupling of magnetic flux from the windings. Undesirable coupling of magnetic flux from open magnetic structures is less likely in low power converters.

In one embodiment of the present invention, a coating of material that has a magnetic permeability greater than free space is applied to the final winding or insulating sleeve. The coating is applied to a sufficient area and with a proper thickness to redirect and confine the magnetic flux from the windings. Redirection and confinement of the magnetic flux from the windings reduces the undesirable coupling of magnetic flux from the windings to circuits. Additional features and benefits of the present invention will become apparent from the detailed description and figures set forth below.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention detailed is illustrated by way of example and not limitation in the accompanying figures.

Figure 1 is a general block diagram that shows the functional elements of a switched mode power converter, illustrating the role of the energy transfer element.

Figure 2 shows a typical construction of an energy transfer element that uses a magnetic element with a closed structure and two windings. The windings occupy sections of the magnetic element that are curved.

Figure 3 shows a construction of an energy transfer element that uses a magnetic element with a closed structure and two windings. The windings occupy sections of the magnetic element that are defined by straight lines.

Figure 4 shows a construction of an energy transfer element that is an assembly of two magnetic elements and two bobbins that contain windings.

Figure 5 shows a typical construction of an energy transfer element that is an assembly of two magnetic elements and one bobbin that contains two windings.

Figure 6 shows a cylindrical magnetic element with one winding.

Figure 7 shows a magnetic element with an open structure that has a cylindrical section with one winding.

Figure 8 shows a magnetic element with an open structure that has one winding coupled to conductive pins that are held by an insulator attached to the magnetic element.

Figure 9 is a pseudo cross-sectional view of the object in Figure 8.

Figure 10 shows a pseudo cross-sectional view of one embodiment of an energy transfer element with two windings according to the teachings of the present invention.

Figure 11 shows a pseudo cross-sectional view of an embodiment of an energy transfer element with two windings separated by an insulating coating according to the teachings of the present invention.

Figure 12 shows a pseudo cross-sectional view of an embodiment of an energy transfer element with two windings separated by an insulating sleeve according to the teachings of the present invention.

Figure 13 shows a pseudo cross-sectional view of an embodiment of an energy transfer element with two windings that are separated and covered by insulating sleeves according to the teachings of the present invention.

Figure 14 shows a pseudo cross-sectional view of an embodiment of an energy transfer element that is coated with a material having a magnetic permeability

substantially greater than free space, covering two windings that are separated and covered by insulating sleeves, according to the teachings of the present invention.

Figure 15 is an electrical circuit diagram of a power converter circuit that shows an embodiment of the simple energy transfer element according to the teachings of the present invention.

DETAILED DESCRIPTION

A method to construct an energy transfer element that simplifies manufacturing is disclosed. In the following description, numerous specific details are set forth to provide a thorough understanding of the present invention. It will be apparent, however, to one having ordinary skill in the art that the specific detail need not be employed to practice the present invention. In other instances, well-known materials or methods have not been described in detail in order to avoid obscuring the present invention.

Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner in one or more embodiments.

The present invention reduces the manufacturing cost of power converters and power supplies. These reductions in cost are most significant in circuits that use few

components, where the cost of the energy transfer element contributes substantially to the total cost of the product.

An embodiment of the present invention uses a magnetic element with a characteristic physical structure that allows turns of wire to be applied by hand or by machine without mechanical complications that would increase the manufacturing cost. It will be understood by one having ordinary skill in the art that there is an infinite variety of physical structures that have this characteristic and could therefore benefit from the teachings of the present invention. A structure with only the most elementary of the essential characteristics will be used by example in this specification to teach the method.

Figure 10 illustrates one embodiment of the present invention. The drawing shows a magnetic element 1000 in cross section that represents an open rod structure that has the cylindrical geometry of magnetic element 800 in Figure 8. It will be understood by one having ordinary skill in the art that the diagram of the magnetic element 1000 also represents a cylinder whose curved surface is not a circle. Furthermore, one having ordinary skill in the art will recognize that the diagram of the magnetic element 1000 also represents a prism. Thus, the long sides 1007 of the magnetic element 1000 could be sections of planes with flat surfaces rather than curved surfaces. The essential property of the magnetic element is that it has an open structure with a section that can easily accept turns of wire that comprises a first winding 1001 directly on its surface without a bobbin. The absence of a bobbin reduces the manufacturing cost.

It is acknowledged in the background information and it is repeated here that magnetic elements can have a coating to protect the surface and to reduce abrasion of

windings. A coating on the surface of the magnetic element is an integral part of the magnetic element; therefore, the surface of the coating shall have the same meaning as the surface of the magnetic element in this specification.

Winding 1001 is typically ordinary magnet wire. One with ordinary skills in the art will recognize magnet wire as a single strand copper wire in standard diameters with an insulating coating. The insulating coating is typically a composition of one or more substances such as enamel, polyimide, nylon, polyurethane or similar insulating materials.

The ends of the winding 1001 are coupled to conductive pins 1003 and 1004. In the embodiment of Figure 10, the conductive pins 1003 and 1004 are held by an insulator 1005. Insulator 1005 is attached to the magnetic element 1000 by means of an adhesive 1006. The pins 1003 and 1004 are electrical terminals for the first winding 1001. Pins 1003 and 1004 also provide mechanical mounting for the energy transfer device when they are inserted into a circuit board. It will be apparent to one with ordinary skill in the art that the pins 1003 and 1004 can be held by means other than the single insulator 1005, and that they can be attached at different places on magnetic element 1000. It will also be apparent to one with ordinary skill in the art that the energy transfer element does not require pins for applications where it is desired to couple to the ends of the first winding by a different means.

A second winding 1002 is applied directly over winding 1001. The ends of second winding 1002 are not coupled to pins. The absence of additional pins reduces the manufacturing cost. The wire of winding 1002 typically has three layers of insulation

that meets the requirements of safety agencies, and is known to those skilled in the art as triple insulated wire. Triple insulated wire requires no additional insulating barrier to isolate a circuit coupled to a first winding from a circuit coupled to the triple insulated wire.

The addition of an insulating material to separate the first winding from the second winding is an alternative embodiment that allows the use of ordinary magnet wire for both windings. The cost of ordinary magnet wire is generally substantially less than the cost of triple insulated wire. The total manufacturing cost can be reduced when there is a lower cost alternative to the use of triple insulated wire. Figure 11 is an embodiment of the present invention that shows a coating of insulating material 1100 that separates the first winding 1101 from the second winding 1102. The insulating material 1100 is of sufficient dimension and dielectric strength to satisfy the requirements of safety agencies for electrical isolation between a first winding and a second winding. The first winding 1101 and the second winding 1102 are ordinary magnet wire.

Figure 12 shows one embodiment of the present invention that has a sleeve of insulating material 1200 between a first winding 1201 and a second winding 1202. The dielectric strength of the insulating material is sufficiently high and the length of the sleeve extends sufficiently past the winding 1202 to meet the requirements of safety agencies for electrical isolation between a first winding and a second winding. The use of a sleeve of insulating material is an alternative to the coating of insulating material 1100 in the embodiment illustrated in Figure 11. One skilled in the art will recognize that in one embodiment the sleeve of insulating material can be a well known product that is a

flexible tube of a crosslinked polymer that shrinks when it is heated to a temperature, known as the shrink temperature, that depends on the particular material. This product has the common name of heat shrink tubing. The heat shrink tubing undergoes a permanent reduction in size after it reaches the shrink temperature. The sleeve after shrinking holds the first winding tightly to the magnetic element and forms a suitable surface to accept the turns of a second winding.

Figure 13 shows one embodiment of the present invention that uses a first sleeve that could be made of heat shrink tubing 1300 to separate a first winding 1301 from a second winding 1302. A second sleeve of heat shrink tubing 1303 covers the second winding 1302. The dielectric strength of the heat shrink tubing is sufficiently high and the length of the tubing extends sufficiently past the winding 1301 to meet the requirements of safety agencies for electrical isolation between a first winding and a second winding.

Figure 14 shows one embodiment of the present invention that has an exterior coating 1400 of a material having magnetic permeability substantially greater than free space. In one embodiment the coating can be comprised of fine particles of magnetic material mixed with a nonmagnetic liquid such that the mixture is substantially homogeneous. The mixture is applied to the exterior of the energy transfer element by painting, dipping, or other suitable means. The mixture changes state from liquid to solid through a curing process that is completed after the coating is applied. The thickness of the coating 1400 and the extent that it covers the exterior surface are determined by the parameters of the manufacturing process. The thickness of the coating and the area that it

covers are selected based on the effective permeability of the coating material to achieve the desired redirection and confinement of the magnetic flux from the windings. The thickness of the coating and the area that it covers can be selected to adjust the inductance of the windings.

Figure 15 is an electrical schematic diagram that shows an embodiment of the present invention in a power converter 1509 that is also a regulated power supply. One having ordinary skills in the art will recognize the elements identified in Figure 15 from the general roles of those elements described in Figure 1, and discussed earlier in this disclosure. A primary switched circuit 1500 couples an input voltage 1501 by means of the integrated circuit 1502 to a first port 1503 of the energy transfer element 1504. Energy is transferred from the first port 1503 that is also a first winding of an energy transfer element in accordance with the teachings of the present invention to a second port 1505 of the energy transfer element. The second port 1505 is also a second winding of the present invention. The second port 1505 is coupled to the secondary switched circuit 1506. Secondary switched circuit 1506 produces a voltage 1507 that one with ordinary skills in the art would couple to an appropriate load. The integrated circuit 1502 contains a power switch with the necessary control circuits to couple the input voltage 1501 with appropriate timing and duration to the first port 1503 in order to regulate the voltage 1507. One with ordinary skills in the art will recognize that information about the voltage 1507 to be regulated is available to the integrated circuit 1502 at the first port 1503 of the energy transfer element 1504. The electrical components in the primary switched circuit 1500 provide information from the first port 1503 to integrated circuit

1502. The integrated circuit 1502 has an internal switch. The integrated circuit 1502 uses the information from the components in the primary switched circuit 1500 to adjust the switching of the internal switch to achieve the desired regulation of the voltage 1507 and or the current flowing in switched circuit 1506. One having ordinary skills in the art will recognize that the integrated circuit 1502 may use one of several control techniques in order to perform the function of adjusting the switching of the internal switch including fixed frequency PWM control, variable frequency control, variable frequency self oscillating control and cycle skipping control. One skilled in the art will also be familiar with the fact that the control technique used by the integrated circuit 1502 is often used to describe the operation of the overall power conversion circuit 1509. In one embodiment, input voltage 1501 is a DC input voltage. In one embodiment, input voltage 1501 is a DC voltage derived from an AC input using suitable rectification and circuitry which will be known to one skilled in the art.

Though not illustrated with additional figures, so as not to obscure the teachings of the present invention, it will be clear to one skilled in the art that an energy transfer element benefiting from the teachings of the present invention can have three or more windings. The additional windings can be used to provide additional power conversion circuit outputs or as shield windings to improve electromagnetic interference performance of the power conversion circuit as will be known to one skilled in the art.

In the foregoing detailed description, the method and apparatus of the present invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto

without departing from the broader spirit and scope of the present invention. The present specification and figures are accordingly to be regarded as illustrative rather than restrictive.

CLAIMS

What is claimed is:

1. An energy transfer element comprising a magnetic element and at least two windings;

the geometry of the magnetic element defining a surface of the magnetic element that is substantially a cylinder,

the windings applied directly to the surface of the magnetic element without a bobbin,

wherein the energy transfer element is part of a switched mode power conversion circuit

wherein the power conversion circuit operates with a fixed frequency

wherein the power conversion circuit operates with a variable frequency

wherein the frequency is varied using a self oscillating mode of operation

wherein the power conversion circuit operates using a cycle skipping control

wherein the power conversion circuit forms part of an AC/DC converter

wherein the AC/DC converter operates with a fixed frequency

wherein the AC/DC converter operates with a variable frequency

wherein the frequency is varied using a self oscillating mode of operation

wherein the AC/DC converter operates using a cycle skipping control

wherein a first winding of the energy storage element is constructed of magnet wire

wherein a second winding of the energy storage element is of triple insulated wire.

wherein a second winding of the energy transfer element is of magnet wire

wherein there is an insulating material between the windings.

wherein the insulating material between the windings is a coating.

wherein the insulating coating can be applied by dip or spray.

wherein the insulating material between the windings is a sleeve.

wherein the sleeve of insulating material can be heat shrink tubing.

wherein the energy transfer element has two electrically conductive pins,

wherein each conductive pin is held to the magnetic element by electrically insulating material

wherein the electrically conductive pins connect to a first winding on the magnetic element

the energy transfer element having a second winding

wherein the second winding is not connected to electrically conductive pins of the energy transfer element.

wherein the energy transfer element includes a third winding

wherein the energy transfer element has at least a partial exterior coating of a material that has a magnetic permeability substantially greater than free space.

2. An energy transfer element comprising a magnetic element and at least two windings; and

the geometry of the magnetic element defining a surface of the magnetic element that is substantially a prism,

the windings applied directly to the surface of the magnetic element without a bobbin,

wherein the energy transfer element is part of a switched mode power conversion circuit

wherein the power conversion circuit operates with a fixed frequency

wherein the power conversion circuit operates with a variable frequency

wherein the frequency is varied using a self oscillating mode of operation

wherein the power conversion circuit operates using a cycle skipping control

wherein the power conversion circuit forms part of an AC/DC converter

wherein the AC/DC converter operates with a fixed frequency

wherein the AC/DC converter operates with a variable frequency

wherein the frequency is varied using a self oscillating mode of operation

wherein the AC/DC converter operates using a cycle skipping control

wherein a first winding of the energy storage element is constructed of magnet wire

wherein a second winding of the energy storage element is of triple insulated wire.

wherein a second winding of the energy transfer element is of magnet wire

wherein there is an insulating material between the windings.

wherein the insulating material between the windings is a coating.

wherein the insulating coating can be applied by dip or spray.

wherein the insulating material between the windings is a sleeve.

wherein the sleeve of insulating material can be heat shrink tubing.

wherein the energy transfer element has two electrically conductive pins,

wherein each conductive pin is held to the magnetic element by electrically insulating material

wherein the electrically conductive pins connect to a first winding on the magnetic element

the energy transfer element having a second winding

wherein the second winding is not connected to electrically conductive pins of the energy transfer element.

wherein the energy transfer element includes a third winding

wherein the energy transfer element has at least a partial exterior coating of a material that has a magnetic permeability substantially greater than free space.